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Vol. 36. 1945.

THE VIBURNUM APHIS, *APHIS (DORALIS) VIBURNI*, SCOP.

By MARGARET G. JONES.

Introduction.

In England, three distinct species of black Aphids, *Aphis (Doralis) fabae*, Scop., *A. (D.) viburni*, Scop., and *Ceruraphis eriophori*, Wlk., are found on the leaves of species of *Viburnum (opulus* type), and have not been clearly distinguished from one another. A fourth species, *A. (D.) mordwilkowi*, was described on the continent by Börner & Janisch (1922), but was later included with *A. fabae*.

A. fabae and *A. viburni* are very similar in appearance, but differ markedly in their life-histories, while *C. eriophori* is larger than these two and differs both in structure and life-history.

Since the first description of a black aphis, *Aphis viburni*, on *Viburnum opulus* by Scopoli (1763), other workers, Fabricius (1775), Linnaeus (1788), Schrank (1801), Mosley (1841), Koch (1857), Kaltenbach (1874), and Schouteden (1906), have mentioned its occurrence. Walker (1850) and Buckton (1879) described an *Aphis viburni* more fully, but in these descriptions, the three species found on *Viburnum* are not distinguished from one another. More recently, Börner (1921), Börner & Janisch (1922), Börner & Schilder (1932), Franssen (1927 & 1930), have described as *A. viburni* a non-migratory black species on *Viburnum opulus* and give, as distinguishing characteristics, long body hairs, the occurrence of papillae on the first 7 abdominal segments and the lack of wings in the males. Börner and Schilder noted, also, that occasional alate sexuparae produce oviparae with thickened hind tibiae. The account given by Theobald (1927) of *A. viburni* is not complete, and the description of the sexual forms is inaccurate.

The present work was undertaken to clear up the identity of *A. viburni* and to distinguish it from the more economically important *A. fabae*. A description of the fundatrix of *C. eriophori*, the form of this species most usually mistaken for *A. viburni*, is also included.

Description and Comparison.

Colonies of black Aphids on *Viburnum* sp. were studied in the field and in the laboratory. For microscopical examination, the different life forms were treated with a mixture of 70 per cent. alcohol and 70 per cent. lactic acid on a water bath, cleared in 95 per cent. phenol and mounted in Berlese's solution. The lengths of the hind tibiae, cornicles, four distal joints of the antenna, marginal and antennal hairs were measured, and the means are given in Tables I—V. The greater length of the hind tibia, as compared with the other limb joints, enabled a greater accuracy of measurement, and therefore only one was measured for each Aphid. The other measurements were based on the number of joints, hairs, or organs available; for antennal joints, cornicle and marginal hairs, this was approximately twice the number of Aphids examined, while for the antennal hairs it was greater (3—4 times). Some specimens were imperfect and did not give a complete set of measurements. This is the same system that has been followed in previous works on *A. (D.) rumicis,* L. (Jones, 1942) and *A. (D.) cognatella,* Jones (1943). The number of papillae on abdominal segments 2-6 of each Aphid examined was counted (maximum 10), and the average number per Aphid is included in the tables. Papillae are always present on segments 1 and 7. The apterae viviparae are described in detail and the other forms only where they differ from these or from *A. fabae.*

Fundatrices (fig. 1).

The fundatrix is about 2 mm. long and has a short 5-jointed antenna, the third joint of which is occasionally divided into two. There is no dorsal pattern, but the dark marginal areas of the abdomen are more distinct than are those of *A. fabae.* Papillae are often present on abdominal segments 2, 3, 4 and sometimes on 5, but the number is irregular and less than on the later summer forms (Table I). The fundatrices of *A. fabae* and *A. viburni* are more nearly identical than any of the other forms, so that distinction is often difficult, for, in addition to the close approximation in the number of papillae, there are few antennal hairs available for measurement.

The fundatrix of *C. eriophori* is about 2¼ mm. long, and is black when mature, but mealy grey when immature. Fig. 3 shows that it differs from the other two species in the dorsal pattern, the arrangement of the hairs and the number of papillae. Extra papillae are often present on the dorsal surface of segments 7, 8 9, and the antenna may be 6-jointed.

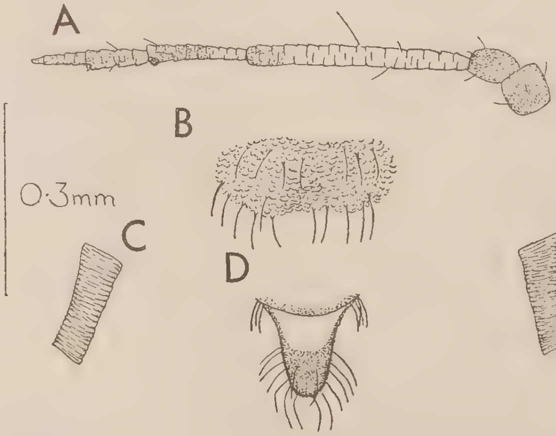

Fig. 1.—Fundatrix of *A. viburni.* A, antenna; B, genital plate; C, cornicles; D, cauda.

TABLE I.

Comparison of the Fundatrices of *A. fabae*, *A. viburni*, and *C. eriophori* on *Viburnum opulus*.

Character	*A. fabae*	*A. viburni*	*C. eriophori*
Length of hind tibia	0.824 mm. (54)	0.815 mm. (59)	0.810 mm. (50)
S.E. ±	0.0103 mm.	0.0082 mm.	0.0056 mm.
Length of cornicles	0.184 mm. (92)	0.177 mm. (105)	0.305 mm. (93).
S.E. ±	0.00185 mm.	0.00163 mm.	0.00209 mm.
Length of ant. joints 3 and 4, joined	0.368 mm. (99)	0.357 mm. (109)	0.279 mm. (57)
S.E. ±	0.0036 mm.	0.00299 mm.	0.00286 mm.
Length of ant. joint 3	—	—	0.192 mm. (37)
S.E. ±	—	—	0.0028 mm.
Length of ant. joint 4	—	—	0.117 mm. (35)
S.E. ±	—	—	0.00239 mm.
Length of ant. joint 5	0.161 mm. (97)	0.144 mm. (110)	0.12 mm. (87)
S.E. ±	0.00197 mm.	0.00207 mm.	0.00118 mm.
Length of ant. joint 6	0.24 mm. (99)	0.221 mm. (106)	0.267 mm. (81)
S.E. ±	0.00199 mm.	0.0017 mm.	0.00253 mm.
Length of ant. hairs	18.17 μ (127)	34.34 μ (114)	18.73μ (125)
S.E. ±	0.421μ	0.791μ	0.409μ
Length of marginal hairs	20.14μ (131)	24.96μ (109)	29.54μ (156)
S.E. ±	0.394μ	0.596μ	0.459μ
No. of papillae on abd. segments 2–6	2.5 (54)	5 (61)	10 (48)
S.E. ±	0.25	0.17	0.29

The actual numbers measured are given in brackets after the mean.

The mean number of papillae for *C. eriophori* includes dorsal pairs which are sometimes present on segments 7, 8 and 9.

Apterae viviparae (fig. 2).

The black colour of the body of the apterous viviparous female may have a dark green or even grey sheen. The aphis is about 2¼ mm. long. The head is darkly chitinised, so also are the 1st, 2nd, distal part of the 4th, 5th and 6th joints of the antenna. The rostrum is dark, with the exception of the proximal 2/3 of the 1st joint, and reaches to the base of the third leg. The compound eyes each bear a prominent tubercle. There are dark bands on the pro- and mesothoracic terga and on abdominal terga 7 and 8, and the large spring apterae have dark bands on the metatergum and abdominal terga 1—6 (fig. 2, A), which shrink to small spots at the bases of the dorsal hairs or disappear altogether in the later summer and autumn forms. Dorsal white wax bands are rarely present on the abdomen. The marginal areas are well defined and bear the marginal hairs. The cornicles and cauda are dark, as are the anal and genital plates. The legs are dark except for the proximal 2/3 of the tibia of all three pairs, together with the femur of the first, which are white in colour. The dorsal and ventral wax glands are well marked. Papillae are always present on the margins of the prothorax and on abdominal segments 1 and 7, and usually on abdominal segments 2, 3, 4 and sometimes on 5 and 6. As a complete set of papillae on the abdominal segments is only occasionally found, it cannot be given as a diagnostic character as stated by Börner and Schilder (1932) and Franssen (1930). The papillae may have two or more lobes. There are 2-4 dorsal longitudinal rows of hairs (fig. 2, A) on the dorsal surface of the body and a group of hairs on the marginal areas, those on the first

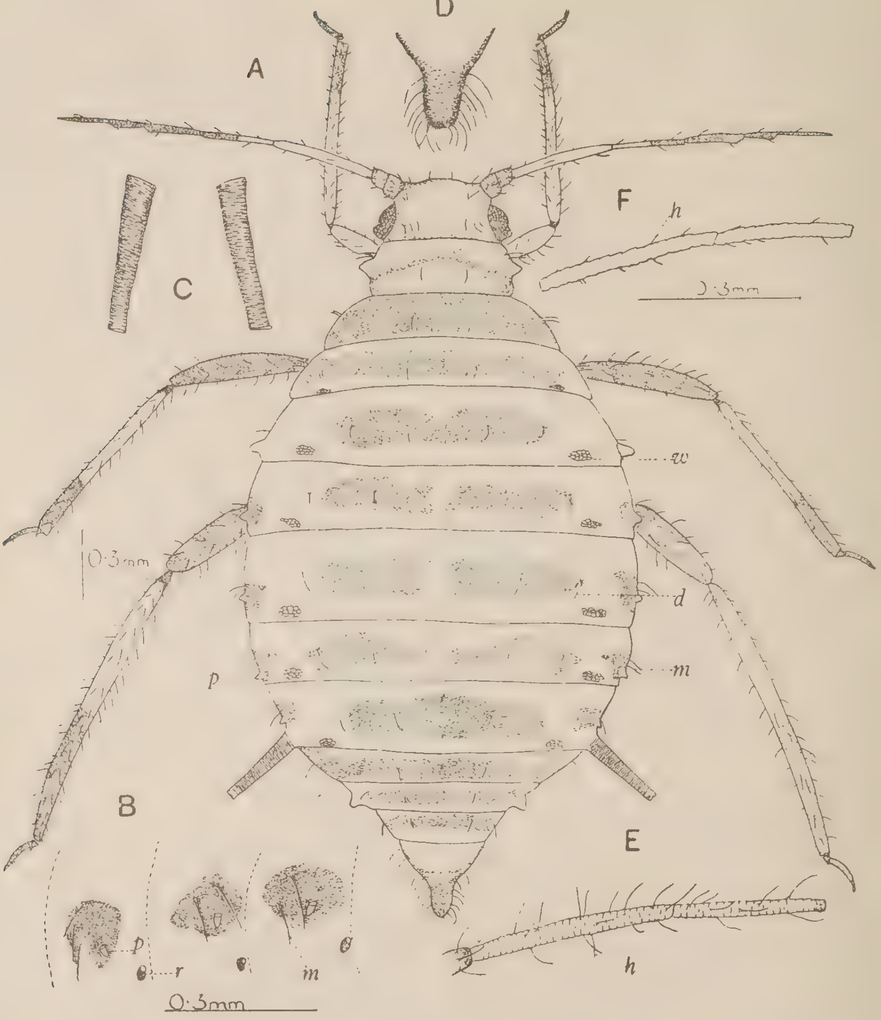

FIG. 2.—A–E, aptera vivipara of *A. viburni*, F of *A. fabae*. A, dorsal view of spring apterous viviparous female. B, side view of abdominal segments 2, 3 and 4. C, cornicles. D, cauda. E and F, antennal joints 3 and 4 ; *d*, dorsal hair ; *h*, antennal hair ; *m*, marginal hair ; *p*, papilla ; *r*, spiracle ; *w*, wax gland.

five abdominal segments numbering 1, 2-3, 2-3, 2-3, 2. Each ventral abdominal sternum bears a double row. The hairs are long and are conveniently measured on the antennae and marginal areas. The lateral spiracles are clearly visible in mounted specimens. The mounted exoskeleton shows a definite reticulation (fig. 4) resembling somewhat that of *A. rumicis*, L., but not quite so pronounced.

The main differences between the apterae viviparae of *A. viburni* and *A. fabae* are: (1) the longer hairs, (2) the consistently greater number of papillae, and (3) the more frequent development of a dorsal abdominal pattern in the spring aptera of *A. viburni*.

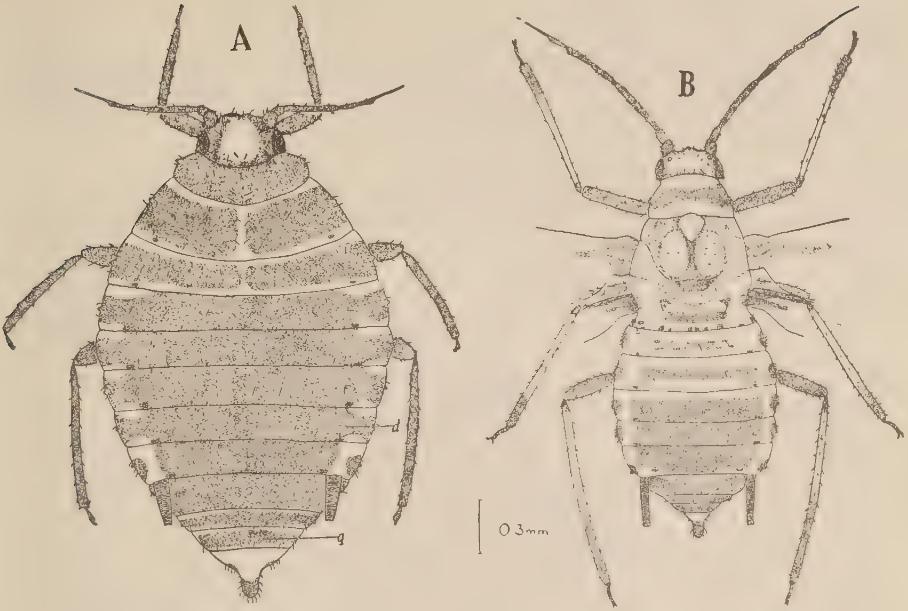

FIG. 3.—*Ceruraphis eriophori.* A, dorsal view of fundatrix. B, dorsal view of alate viviparous female ; *d*, dorsal hair ; *q*, dorsal papilla.

TABLE II.
Comparison of the Apterae Viviparae of *A. fabae* and *A. viburni* on *Viburnum opulus.*

Character	*A. fabae*	*A. viburni*
Length of hind tibia .. S.E. ±	1.03 mm. (58) 0.0184 mm.	1.11 mm. (55). 0.0134 mm.
Length of cornicles .. S.E. ±	0.258 mm. (118) 0.00498 mm.	0.266 mm. (110). 0.0043 mm.
Length of ant. joints 3 and 4 .. S.E. ±	0.326 mm. (114) : 0.212 mm. (109) 0.00502 mm. : 0.00132 mm.	0.346 mm. (103) : 0.240 mm (104). 0.00446 mm. : 0.00357 mm.
Length of ant. joints 5 and 6.. S.E. ±	0.199 mm. (104) : 0.423 mm. (80) 0.00492 mm. : 0.00523 mm.	0.208 mm. (100) : 0.472 mm. (87). 0.00245 mm. : 0.00473 mm.
Dorsal body pattern ..	Faint or absent. Often wax bands on abdomen.	Dark bands on abdomen in early summer forms, reduced later in the season. Rarely wax bands.
Number of papillae on abdominal segments 2–6 .. S.E. ±	2 (64).. 0.144 ..	7 (63). 0.179.
Length of ant. hairs .. S.E. ±	30.18μ (234) 0.565μ	58.15μ (199). 0.612μ.
Length of marginal hairs .. S.E. ±	52.86μ (176) 0.928μ	68.63μ (143). 0.535μ.

The actual numbers measured are given in brackets after the mean.

Alatae viviparae (fig. 4).

The alate viviparous females are strongly chitinised. The antennae are black and bear secondary sensoria on joints 3 and 4. Three simple ocelli are present on the head as well as the compound eyes. The thorax is modified for flight, and the

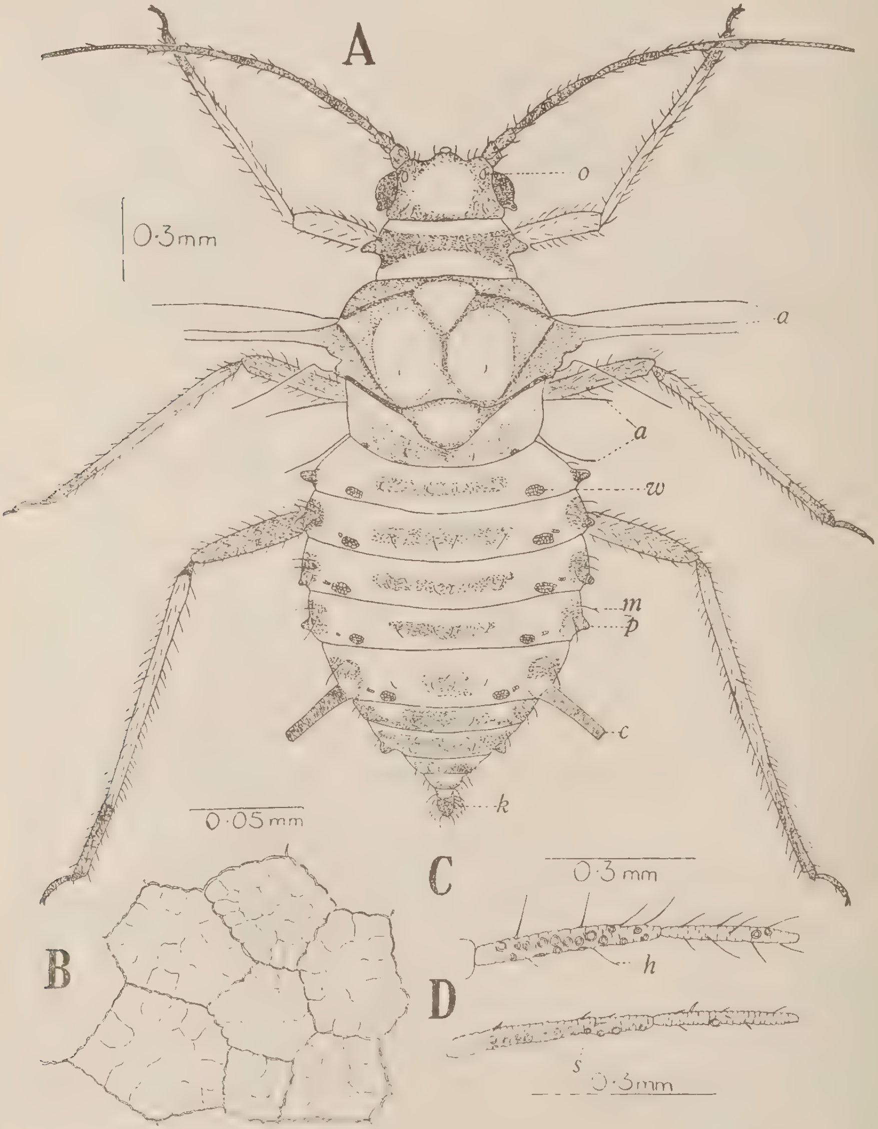

Fig. 4.—Alata vivipara A–C of *A. viburni*, D, of *A. fabae*. A, dorsal view, with wing bases only. B, reticulations on the body surface of the abdomen. C and D, 3rd and 4th joints of the antenna; *a*, wing base; *c*, cornicle; *h*, hair; *k*, cauda; *m*, marginal hair; *o*, ocellus; *p*, papilla; *s*, secondary sensorium; *w*, wax gland.

wings are of the Aphis type. The dorsal abdominal pattern is similar to that of the apterae viviparae and of the same type as the alatae viviparae of *A. fabae* and *A. cognatella* (Jones, 1942 and 1943). As shown in fig. 3, the light brown alatae of *C. eriophori* differ markedly from those of *A. viburni*.

TABLE III.

Comparison of the Alatae Viviparae of *A. fabae* and *A. viburni* on *Viburnum opulus*.

Character	*A. fabae*	*A. viburni*
Length of hind tibia	1.196 mm. (59)	1.138 mm. (58).
S.E. ±	0.0116 mm.	0.0085 mm.
Length of cornicles	0.227 mm. (118)	0.225 mm. (116).
S.E. ±	0.0029 mm.	0.0021 mm.
Length of ant. joints 3 and 4	0.358 mm. (107) : 0.261 mm. (104)	0.342 mm. (107) : 0.253 mm. (97).
S.E. ±	0.0033 mm. : 0.0023 mm.	0.0028 mm. : 0.0024 mm.
Length of ant. joints 5 and 6	0.234 mm. (92) : 0.481 mm. (80)	0.22 mm. (94) : 0.483 mm. (82).
S.E. ±	0.0022 mm. : 0.0029 mm.	0.0018 mm. : 0.00317 mm.
Number of papillae on abdominal segments 2–6	3 (58)	7 (59).
S.E. ±	0.188	0.148.
Dorsal body pattern	Present	Present—the same type as that of *A. fabae*.
Length of ant. hairs	27.37μ (91)	57.42μ (205).
S.E. ±	0.603μ	0.511μ.
Length of marginal hairs	46.27μ (66)	67.22μ (149).
S.E. ±	1.31μ	0.521μ.
No. of sensoria on ant. joints 3 and 4	15.1 (111) : 0.43 (90)	19.5 (98) : 1.7 (101).
S.E. ±	0.2245 : 0.077	0.356 : 0.176.

The actual numbers measured are given in brackets after the mean.

Sexuparae.

The sexuparae are apterous and are similar in structure to the autumn apterae viviparae.

Oviparae (fig. 5).

The oviparae are slightly smaller than the apterae viviparae, but the body is often elongated behind the cornicles owing to the presence of unlaid eggs. The antennae are usually 6-jointed, but the division between the third and fourth joints may be incomplete. The hind tibiae are not swollen as are those of *A. fabae* (fig. 5, D, E) and bear fewer pseudosensoria. In many of the individuals examined, no pseudosensoria at all were present. The occurrence of winged sexuparae producing oviparae with paddle-shaped hind tibiae (Börner & Schilder, 1932) like those of *A. fabae* has not been encountered. The genital plate is bifid. One to three ripe eggs were seen in the body of one female. The oviparae of *C. eriophori* are light green in colour and have swollen hind tibiae.

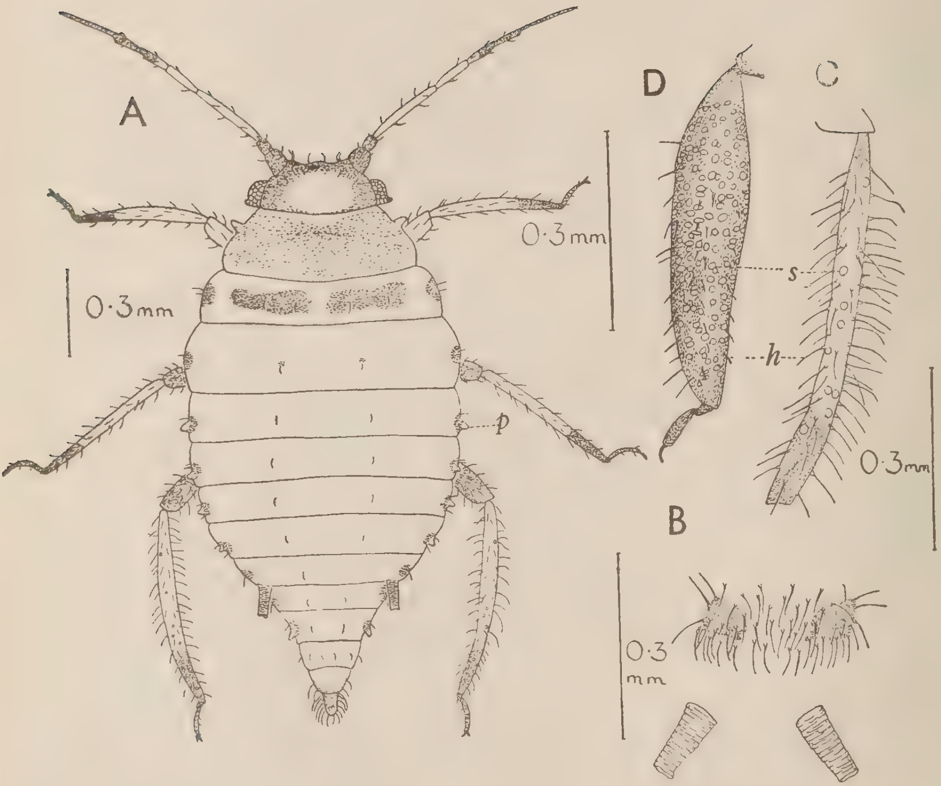
A
D
C
B
0·3mm
0·3mm
0·3mm
0·3
mm
p
s
h

FIG. 5.—Ovipara A–C of *A. viburni*, D of *A. fabae*. A, dorsal view. B, genital plate and cornicles. C and D, hind tibia; *h*, hair; *p*, papilla; *s*, pseudosensoria.

TABLE IV.

Comparison of the Oviparae of *A. fabae* and *A. viburni* on *Viburnum opulus.*

Character	*A. fabae*	*A. viburni*
Length of hind tibia	0.660 mm. (56)	0.645 mm. (50).
S.E. ±	0.0052 mm.	0.0081 mm.
Length of cornicles	0.122 mm. (106)	0.103 mm. (98).
S.E. ±	0.0011 mm.	0.0014 mm.
Length of ant. joints 3 and 4	0.20 mm. (102) : 0.131 mm. (103)	0.161 mm. (92) : 0.102 mm. (90).
S.E. ±	0.0021 mm. : 0.00166 mm.	0.0022 mm. : 0.0014 mm.
Length of ant. joints 5 and 6	0.153 mm. (105) : 0.324 mm. (103)	0.1134 mm. (92) : 0.301 mm. (95).
S.E. ±	0.00163 mm. : 0.0011 mm.	0.0014 mm. : 0.0018 mm.
No. of papillae on abdominal segments 2–6	0 (55)	6 (58).
S.E. ±	—	0.177.
Length of ant. hairs on joints 3 and 4	23.09μ (152)	39.68μ (132).
S.E. ±	0.361μ	0.491μ.
Length of marginal hairs	40.39μ (102)	60.99μ (128).
S.E. ±	0.584μ	0.614μ.
Number of pseudo-sensoria on hind tibia	>100	0–50. Of those counted, 42 per cent. had no sensoria.

The actual numbers measured are given in brackets after the mean.

Males (fig. 6).

Although the males are apterous, they are strongly chitinised, often having the complete dorsal pattern of the alatae viviparae. Sensoria are present on the 3rd, 4th and 5th antennal joints, but are fewer in number than those on the antennae of the alate males of *A. fabae.* These apterous males are similar in appearance to the males of *A. rumicis* (Jones, 1942). The males of *C. eriophori* are alate.

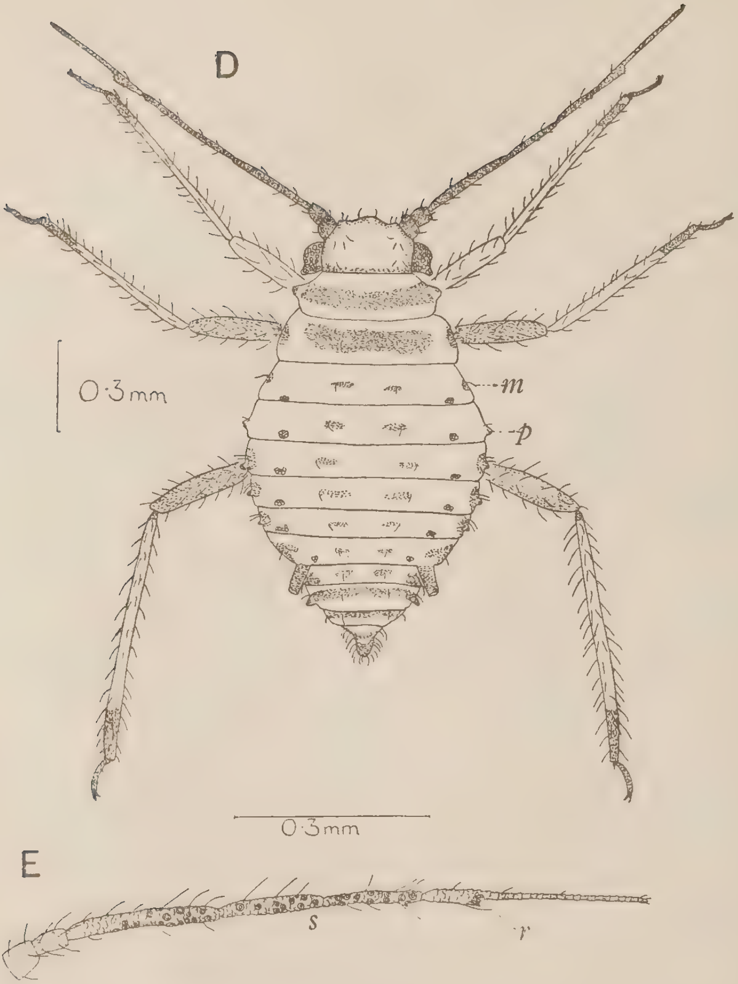

Fig.6.—Male of *A. viburni*. D, dorsal view. E, antenna; *m*, marginal hair; *p*, papilla; *s*, secondary sensorium; *r*, rhinarium.

Eggs.

The eggs are shining black and found in the axils of the leaf buds and in crevices in the bark. They are very similar to those of *A. fabae*.

TABLE V.

Measurements of the Males of *A. viburni.*

(The males of *A. fabae* are alate and produced on the summer host, and are therefore not strictly comparable.)

Character	*A. viburni*
Length of hind tibia	0.748 mm. (52).
S.E. ±	0.00878 mm.
Length of cornicles	0.085 mm. (105).
S.E. ±	0.0014 mm.
Length of antennal joints 3 and 4	0.282 mm. (99) : 0.182 mm. (99).
S.E. ±	0.0047 mm. : 0.0025 mm.
Length of antennal joints 5 and 6	0.156 mm. (98) : 0.36 mm. (97).
S.E. ±	0.00171 mm. : 0.00266 mm.
Dorsal body pattern	Present—dorsal abdominal bands as in the alata vivipara.
Number of papillae on abdominal segments 2–6 ..	6 (53).
S.E. ±	0.19.
Number of sensoria on antennal joints 3	0–40. Mean = 7 (112); no reliable S.E. given.
Number of sensoria on antennal joint 4	0–27. Mean = 7 (100); no reliable S.E. given.
Number of sensoria on antennal joint 5	0–17. Mean = 6 (100).
S.E. ±	0.352.
Length of antennal hairs	38.23μ (150).
S.E. ±	0.5016μ.
Length of marginal hairs	58.69μ (110).
S.E. ±	0.621μ.

The actual numbers measured are given in brackets after the mean.

Nymphs.

Nymphs are generally a slatey grey in colour, so that young summer colonies of *A. viburni* can often be distinguished from those of *A. fabae* where the individuals are black or dark green in colour.

The first instar has a 4-jointed antenna and is about ½ mm. long. The abdominal papillae are already well marked and are distinguishable in all the instars. The second instar is about 1 mm. long and has a 5-jointed antenna. The third instar of the aptera vivipara has increased to about 1½ mm. long, while the fourth is about 1¾ mm. and has a 6-jointed antenna, but the cauda is still rounded. The wing buds of the alatae viviparae are present in the third and fourth instars, and the dorsal surface of the abdomen of the fourth bears transverse white wax bands.

Biology.

A. viburni hatches out towards the end of March, and the young nymphs are found on the lower surface of the young leaves of *V. opulus.* The fundatrices mature in about three weeks, if the weather conditions are favourable. The early colonies are very difficult to distinguish from those of *A. fabae,* and individuals of the two species may feed together on the same leaf. The fundatrix of *C. eriophori* is, however, quite distinct and the young nymph causes a marked leaf curl, in which the fundatrix remains and the young alatae are produced and feed. If these fawn alate nymphs are removed to another leaf, they do not cause it to curl, although they are able to feed successfully. Only large colonies of the other two species cause the young leaves to curl.

Young colonies produced by mature *A. viburni* are grey in colour compared with the black or dark green young of *A. fabae.* Alatae viviparae of both species appear in May and June and by the middle of June colonies found on *V. opulus* are generally those of *A. viburni* as the alatae viviparae of the other two species have flown to the summer hosts. Colonies of *A. viburni* are found on *V. opulus* throughout the summer and autumn. Few alatae are produced after the large spring outburst.

In the field, *A. viburni* is more frequently found in urban than country areas, where the commonest species of *Viburnum* is the sterile guelder rose, *V. opulus* var. *sterile.*

Although *A. viburni* occurs mainly on the acerifoliate species of *Viburnum,* colonies have been obtained on other plants experimentally. Table VI gives the results of transference experiments, where a single aptera vivipara or alata vivipara was placed on the leaf of a small potted plant, a known host of *A. fabae,* and enclosed in a muslin sleeve The progeny, if any, was recorded every few days. On two species only, colonies survived into the second generation after the start of the experiment; these were on *Rumex obtusifolius* and *Euonymus europaeus* (cf. Börner & Schilder, 1932). On *Vicia faba,* the chief early summer host of *A. fabae,* no young were produced. From these results, it appears that *A. viburni* is more specific in its choice of host plant than *A. fabae.*

TABLE VI.

The Results of Transference Experiments of single Individuals of *A. viburni* placed on some of the Summer Host Plants of *A. fabae.*

Host plant	No. of trials	No. of adults which produced young	No. of colonies reaching maturity and producing a second generation
Vicia faba	23	0	0
Chenopodium album	13	1	0
Rumex obtusifolius	11	3	2
Papaver rhoeas	2	2	0
Solanum nigrum	11	0	0
Cirsium arvensis	8	0	0
Beta vulgaris—			
Crop	4	1	0
Seed	4	1	0
Capsella bursa-pastoris	11	1	0
Euonymus europaeus	8	6	4
Total	95	15 (15.8 per cent.)	6 (6.2 per cent.)

Apterous males and oviparae appear in September. In the early autumn both sexual forms and some apterae viviparae are produced by the same apterous sexupara. The absence of alatae in the autumn colonies distinguishes them from those of *A. fabae.* One to four winter eggs are laid by the ovipara in the axils of the buds or in the crevices of the twigs.

Summary.

1. The Viburnum aphis, *Aphis (Doralis) viburni*, Scop., is described and compared with two other species, *A. fabae*, Scop., and *Ceruraphis eriophori*, Wlk., also found on *Viburnum opulus*.

2. Transference experiments show that colonies can be established artificially on *Euonymus europaeus* and *Rumex obtusifolius*, but not on other common host plants of *A. fabae*.

3. The sexupara is apterous and produces mixed colonies, thus differing from *A. fabae* where an alate gynopara produces only oviparae, the males arising from an apterous mother on the summer host.

Acknowledgment.

My thanks are due to Mr. F. G. W. Jones of the School of Agriculture, Cambridge, for procuring some specimens and for reading through the script.

References.

Börner, C. (1921.) Mitt. biol. Anst. (Reichsanst.) Berl., **21**, p. 198.

—— & Janisch, R. (1922.) NachrBl. dtsch. PflSchDienst, **2**, p. 65.

—— & Schilder, F. A. (1932.) In Sorauer, P. Handbuch der Pflanzenkrankheiten, **5**, p. 551.

Buckton, G. B. (1879.) Monograph of British Aphides, **2**, p. 77.

Fabricius, J. C. (1775.) Systema Entomologiae, no. 18, p. 737.

Franssen, C. J. H. (1927.) Tijdschr. PlZiekt., **33**, p. 193.

——. (1930.) Z. angew. Ent., **17**, p. 106.

Jones, M. G. (1942.) Bull. ent. Res., **33**, p. 5.

——. (1943.) Bull. ent. Res., **34**, p. 213.

Kaltenbach, J. H. (1874.) Die Pflanzenfeinde aus der Classe der Insecten Stuttgart, p. 300.

Koch, C. L. (1857.) Die Pflanzenläuse, Nürnberg, p. 122.

Linnaeus, C. (1788.) Systema Naturae, Gmel. Edition, **1**, p. 2208.

Mosley, O. (1841.) Gdnr's Chron., 1841, p. 684.

Schouteden, H. (1906.) Mém. Soc. ent. Belg., **12**, p. 221.

Schrank, F. (1801.) Fauna Boica, **2**, no. 1203, p. 111.

Scopoli, J. A. (1763.) Entomologia Carnicolica, p. 136.

Theobald, F. V. (1927.) Aphididae of Great Britain, **2**, p. 114.

Walker, F. (1850.) Ann. Mag. nat. Hist., (2) **6**, p. 41.

THE PENETRATION OF DERRIS THROUGH THE SPIRACLES AND CUTICLE OF *MELOPHAGUS OVINUS*, L.

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Introduction.

It is well known that insects vary in their susceptibility to derris, many being unaffected by the drug and, in extreme cases, feeding on stored derris root (Roark, 1939). The mode of entry into the insect of the toxic principle of derris is not fully understood. Tischler (1935) has suggested that entry of derris into the body may be effected through the alimentary canal, the spiracles and tracheal system and the external cuticle, and that the non-susceptibility of certain insects to derris appears to be due to its failure to penetrate the body rather than to any inherent resistance to the drug on the part of the insect.

There seems little doubt that, in the case of certain Lepidopterous larvae, derris can act as a stomach poison. Both Shepard & Campbell (1932) and Swingle (1934) obtained positive results by feeding rotenone or derris in leaf sandwiches to silkworms and cabbage worms, and Tischler (1935) reported that Lepidopterous larvae fed with water extracts of derris through a pipette died of derris poisoning. On the other hand, Woke (1938), working with the southern armyworm, *Prodenia eridania*, Cram., found that the insect remained normal after ingesting 5 mg. of rotenone in a turnip leaf sandwich and that most or all of the drug was eliminated with the faeces. Furthermore, there are a large number of insects listed by Roark (1939) as pests of stored derris root in which absorption of rotenone through the alimentary canal must be negligible.

Where insects with suctorial mouth parts are susceptible to derris, the mode of entry of the drug cannot be by ingestion and must take place either through the external cuticle or through the respiratory system or through both. The sheep ked, *Melophagus ovinus*, is a blood-sucking parasite very susceptible to derris. It was, therefore, chosen as a suitable test insect for research on the penetration of derris. This work was preceded by a study of the respiratory mechanism of this insect, a full account of which will be published at a later date.

The experiments recounted here show the relative importance of the cuticle and respiratory system as routes for the entry of derris into the insect body. They also indicate the need for careful selection of the type of insecticidal dust most suitable for the control of other pests.

Technique.

The procedure adopted for observing the treated insect under controlled conditions was as follows:

Mature keds were collected from sheep, anaesthetised with pure ether and placed in rows on microscope slides thinly coated with paraffin wax (M.P. 60° C.). By heating the slides on a hot plate until the wax just melted and then cooling rapidly, the distal segments of the 2nd and 3rd pairs of legs and the ventral surface of the abdomen of the keds were cemented to the glass. A small drop of wax (M.P. 40° C.) was then placed over each spiracle to be sealed and melted by radiant heat from a white hot needle when the wax could be seen to fill the atrium of the spiracle.

The keds on the slides were then dusted with commercial ground derris root from a shaker made by stretching a piece of muslin over the mouth of a specimen tube. This method was found to be most satisfactory and produced a cloud of derris dust falling fairly evenly on the insects. After dusting, the derris on the dorsal surface of the abdomen was removed by lightly brushing with a small camel hair brush to enable observations to be made on the heart beat.

The slides were placed in the compartments of the chamber (see fig. 1), which was designed to enable keds to be observed under the binocular microscope in various gas mixtures. The chamber was covered by a sheet of thin glass and an air-tight seal was made by running molten wax along its edges.

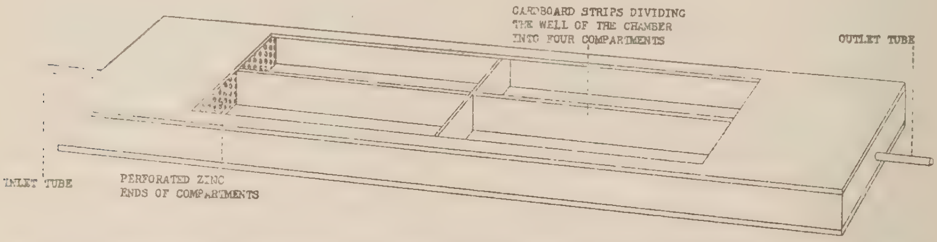

CARDBOARD STRIPS DIVIDING THE WELL OF THE CHAMBER INTO FOUR COMPARTMENTS
OUTLET TUBE
INLET TUBE
PERFORATED ZINC ENDS OF COMPARTMENTS

Fig. 1. Chamber for observing keds in different gas mixtures. The glass cover has been omitted.

It was found that, during the course of its action, derris gave rise to three distinct symptoms which presumably indicated the presence of definite concentrations of the drug in the insect in each case. The first symptom was a lack of co-ordination of limb movement accompanied by an irregularity of the heart beat. The second was the final cessation of limb movement in response to a tap on the glass cover of the chamber. The third was death which was assumed to take place at the final cessation of heart beat. The beating of the heart in the fed adult ked can be seen quite clearly through the transparent chitin of the abdomen with the medium power of a binocular microscope. In newly emerged and unfed keds, however, the chitin of the abdomen is wrinkled and the setae are so closely set as to render observation of the heart difficult. For this reason only mature keds were used in the following experiments.

The Entry of Derris through the Spiracles.

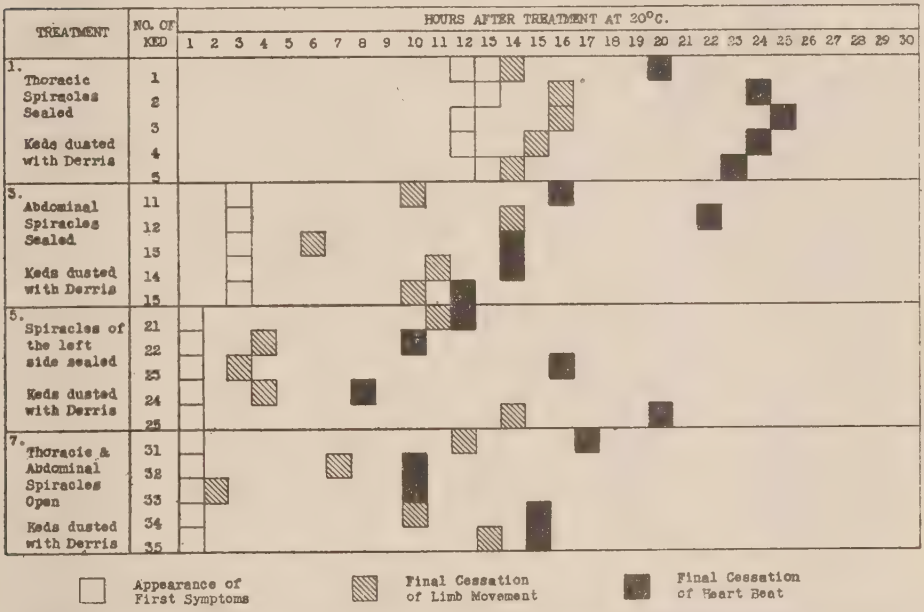
To show that derris enters the tracheal system in *Melophagus ovinus*, a comparison was made between the susceptibility to derris dust of keds breathing normally with that of keds breathing (a) through the abdominal spiracles only, (b) through the thoracic spiracles only, and (c) through the spiracles of the left side only. As a check on the possible effects of sealing the spiracles, groups of keds similarly treated were observed as undusted controls.

The experiment was carried out at a temperature of 20° C., and detailed observations on the condition of both dusted and undusted keds were made at hourly intervals. A summary of the results obtained is given in Table I.

The undusted keds remained normal throughout the experiment.

It will be seen from the table that the sealing of either the thoracic or the abdominal spiracles decreased the susceptibility of the insect to derris. As all the keds in this experiment were under identical conditions both with regard to their ability to move and the temperature of their surroundings the differences observed cannot have been due to variations in the internal action of the derris. It must be assumed, therefore, that the sealing of certain of the spiracles produced a reduction in the rate of entry of derris into the body and hence that penetration of the dust took place through those spiracles remaining open. It is not suggested, however, that this is the only mode of entry.

TABLE I.



Variations in susceptibility of keds to derris produced by sealing the thoracic or abdominal spiracles

It will be noticed that decreased susceptibility to derris occurred in only those groups in which all the thoracic or all the abdominal spiracles were sealed. The keds in which the spiracles of the left side were sealed, on the other hand, remained as susceptible to derris as those breathing through all their spiracles. This is attributed to the fact that, as tracheal ventilation normally takes place in the ked in a forward direction, closure of either the thoracic or abdominal spiracles interferes with the directed flow of air, whereas closure of the spiracles of one side does not.

Thus, where all the spiracles function, the abdominal spiracles serve only for inspiration and derris dust is sucked in through them continually, but where either the thoracic or the abdominal spiracles serve both for inspiration and expiration, as in groups 1 and 3 of this experiment, the derris taken in during inspiration tends to be expelled during expiration. If this were not so, then sealing of the spiracles of the left side must inevitably have reduced the susceptibility of the ked to derris. The air passing through the spiracles of the right side at twice the normal speed undoubtedly carried with it a quantity of derris equal to that entering all the spiracles in the normal keds.

The difference in susceptibility observed between those keds with the thoracic spiracles sealed and those with the abdominal spiracles sealed is due to the difference in structure of the thoracic and abdominal spiracles. The thoracic spiracles are both larger and less well protected against the entry of dust than the abdominal spiracles.

It is evident, therefore, that entry of derris into the tracheal system depends on the presence of an inwardly directed air current through the spiracles and that the amount entering will vary according to the velocity of that current and the structure of the spiracles.

The Effect of muscular Activity, Carbon Dioxide and Temperature on the Susceptibility of Keds to Derris.

If, as has been suggested in the previous experiment, the susceptibility to derris of keds breathing normally varies with the volume of air passing through the tracheal system, then any factor tending to increase the rate of respiration should also increase the susceptibility of the ked to derris. In this experiment the effect of three such factors—namely, muscular activity, carbon dioxide and temperature—on the rate of action of derris has been studied.

Carbon dioxide was stated by Hazelhoff (1926, 1928) to be a specific stimulus to the respiratory centre in insects, and other workers, among them Cotton (1932), McGovran (1932), Mellanby (1934), Wigglesworth (1935, 1941), Kitchel & Hoskins (1935), and Herford (1938), have shown that carbon dioxide in low concentrations not only induces spiracles to remain open but also increases the rate of the breathing movements of a variety of insects. As it was shown by Lee (1925, 1927) that the respired air of certain Orthoptera contained 4 per cent. carbon dioxide, it was thought that a concentration of 5 per cent. carbon dioxide should prove an adequate respiratory stimulant in *Melophagus ovinus* without causing subsequent anaesthesia.

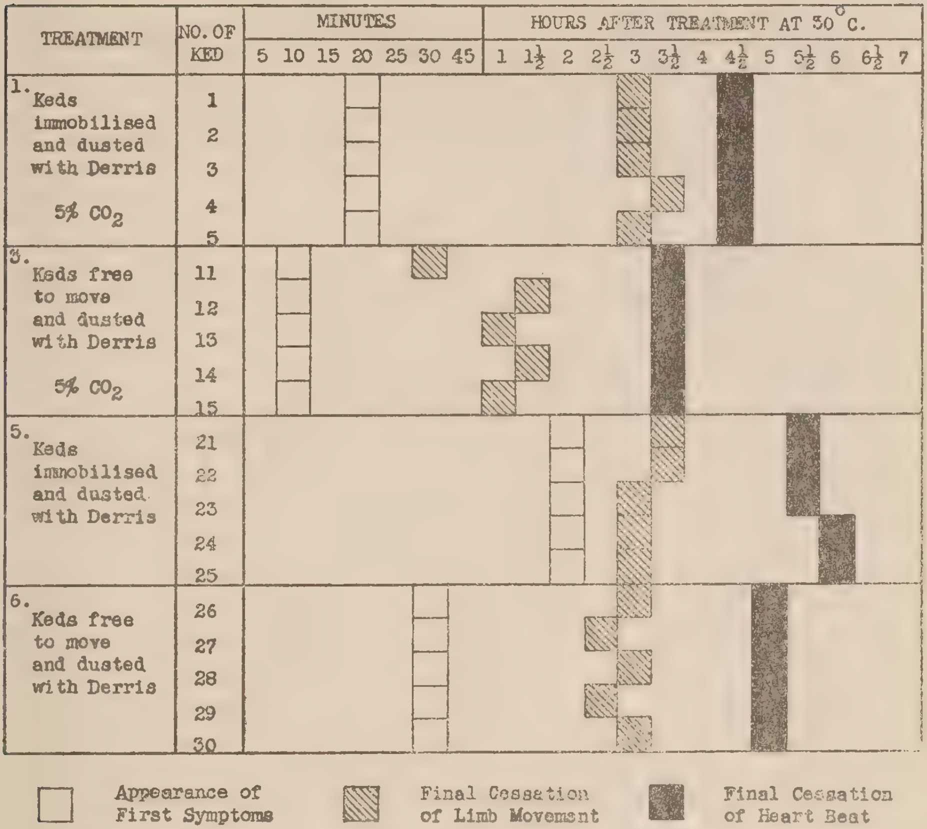
Two groups of keds free to move, and two immobilised by waxing on to microscope slides were dusted with derris. One group from each series was observed in air and the other in 5 per cent. carbon dioxide. In this experiment the temperature was raised to 30° C. for comparison with the last experiment which was carried out at 20° C. A corresponding series of undusted control groups were observed for comparison with those dusted with derris.

Observations on the condition of the keds were made at five-minute intervals for the first half-hour, at fifteen-minute intervals for the second half-hour and thence at each succeeding half-hour. A summary of the results obtained is given in Table II.

The undusted keds remained normal throughout the experiment.

It will be seen from this table that the activity of the keds in groups 3 and 6 in comparison with the immobility of those in groups 1 and 5 produced an increase in the rate of action of the derris. Similarly the presence of 5 per cent. CO_2 increased the susceptibility to derris of the keds in groups 1 and 3 in comparison with those of groups 5 and 6. It is evident, therefore, that muscular activity and the presence of carbon dioxide by producing an increased rate of respiration in the insect, also increased the rate of entry of derris into the body. In addition, a comparison between group 5, Table II, and group 7, Table I shows that a rise in temperature of 10° C. decreased the average time of kill of keds otherwise similarly treated from 13 hours to 5½ hours. It is clear, therefore, that the rate of respiration of the ked plays a major part in determining the susceptibility of the insect to derris and that this is increased by the presence of carbon dioxide, by similar increases in the activity of the insect, or by a rise in temperature.

Table II.



The effect of muscular activity, CO_2 and temperature on the susceptibility of keds to derris.

The Penetration of Derris through the Cuticle.

It has been shown in the previous experiments that derris dust penetrates the spiracles of *Melophagus ovinus,* and it now remains to test the degree of absorption through the cuticle.

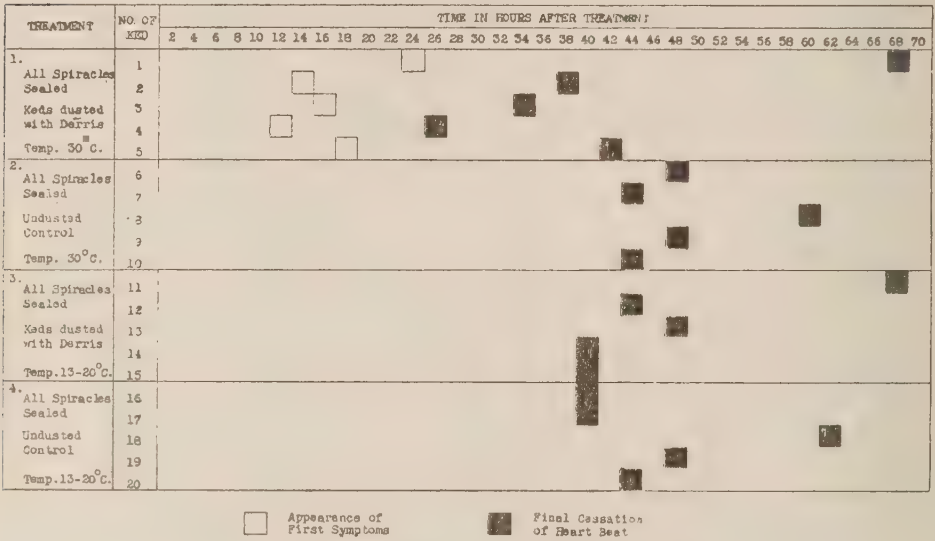
In this experiment keds with all their spiracles sealed were dusted with derris. It was found necessary, in this instance, to allow the keds to recover completely from the anaesthetic before sealing the spiracles. If this precaution was not observed, then the elimination of ether from the tracheal system was unable to take place and death followed within a few hours. As the sealing of the spiracles produced asphyxiation of the keds within a few minutes, observations were confined to the heart beat.

Observations were made on both dusted and undusted keds every two hours at laboratory temperature which varied from 13-20° C. and at 30° C.

It is evident from the results of this experiment that at 30° C. derris does enter the ked by some means other than through the spiracles.

The irregularity of the heart beat observed in the keds of group 1 suggests that death was due, at least in part, to derris poisoning. Furthermore, in four keds out of the five in that group, death occurred earlier than in the members of the corresponding control. Where the keds were kept at laboratory temperature, however, no symptoms of derris poisoning were observed and there was no significant difference in the time of death of those keds dusted with derris and those in the undusted control.

Table III.



The penetration of derris through the cuticle.

It seems certain that in group 1 the derris resin was absorbed directly through the cuticle of the ked. Diffusion through the wax filling the spiracles was unlikely to have occurred as derris resin is substantially insoluble in the hydrocarbons of which the wax is composed. It might be expected that the rate of entry of derris resin through the cuticle would be increased by a rise in temperature when not only would the lipoid layer covering the chitin become less viscous but the rate of diffusion itself would be increased.

It appears, therefore, that the penetration of derris through the cuticle at 30° C. is of secondary importance in comparison with penetration through the tracheal system and at low temperature may be considered as negligible.

Conclusions.

It has been shown that in *Melophagus ovinus* by far the greater proportion of the derris entering the body passes through the spiracles and tracheal system and that the quantity is governed by both the size and structure of the inspiratory spiracles and the rate of flow of the inspired air. The entry of derris through the respiratory system in any given insect, therefore, will depend on *(a)* whether the insect breathes by tracheal ventilation or by diffusion, and *(b)* whether the structure of the inspiratory spiracles will allow the passage of a fine dust into the tracheal system.

It has also been shown that derris can penetrate the external cuticle of the ked slowly at 30° C., but not at 20° C., and it is postulated that the rate of penetration varies with the hardness of the waxes covering the cuticle.

The susceptibility of insects to derris is determined, therefore, by at least four factors; firstly, the mode of breathing; secondly, the form of the spiracles; thirdly, the hardness of the waxes covering the cuticle; and, fourthly, the ability of the insect to ingest derris resin and absorb it through the walls of the alimentary canal in a form toxic to the insect. It is clear that in different insects not all these modes of entry will be operative at least to the same degree, and the wide differences in susceptibility of insects to derris are undoubtedy due to this cause.

A study of the structure of insects to be controlled by insecticidal dusts should yield information which will lead to a better understanding of the physical nature of dusts to be used in any particular case. Where the structure of the respiratory system is such as to enable dusts to penetrate the spiracles, then a dust composed of small light particles not adhering to the insect is likely to prove more effective than one in which the particles are larger and adherent. On the other hand, where the spiracles are well protected, penetration of the insecticide through the external cuticle becomes of major importance, and in this instance a dust with particles capable of adhering closely to the insect is essential.

Summary.

In *Melophagus ovinus*, derris dust is shown to be absorbed through the spiracles and tracheal system. The amount of dust entering the tracheae is governed by the structure of the inspiratory spiracles and the rate of flow of the inspired air.

Factors stimulating the rate of respiration of the insect—*i.e.*, increased muscular activity, the presence of 5 per cent. carbon dioxide and a rise in temperature, increase the rate of entry of derris into the body.

Penetration of derris takes place slowly through the external cuticle at 30° C., but not at all at 20° C. It is postulated that the entry of derris through the cuticle probably depends on the hardness of the lipoid layer.

References.

Cotton, R. T. (1932.) The relation of respiratory metabolism of insects to their susceptibility to fumigants.—J. econ. Ent., **25**, pp. 1088–1103.

Hazelhoff, E. H. (1926.) On a new form of breathing regulation (regulation of diffusion) in Insects and Arachnida.—Proc. Acad. Sci. Amst., **29**, pp. 492–496.

——. (1928.) Carbon dioxide a chemical accelerating the penetration of respiratory insecticides into the tracheal system by keeping open the tracheal valves.—J. econ. Ent., **21**, p. 790.

Herford, G. M. (1938.) Tracheal pulsation in the flea.—J. exp. Biol., **15**, pp. 327–338.

Kitchel, R. L. & Hoskins, W. M. (1935.) Respiratory ventilation in the cockroach in air, in carbon dioxide and in nicotine atmospheres.—J. econ. Ent., **28**, pp. 924–933.

LEE, M. O. (1925.) On the mechanism of respiration in certain Orthoptera.—J. exp. Zool., **41**, pp. 125–154.

——. (1927.) A note on the mechanism of respiration in the Orthoptera.—J. exp. Zool., **49**, pp. 319–320.

McGOVRAN, E. R. (1932.) The effect of some gases on the tracheal ventilation of grasshoppers.—J. econ. Ent., **25**, pp. 271–276.

MELLANBY, K. (1934.) The site of water loss from insects.—Proc. roy. Soc. (B), **116**, pp. 139–149.

ROARK, R. C. (1939.) Insect pests of derris.—J. econ. Ent., **32**, pp. 305–309.

SHEPARD, H. H. & CAMPBELL, F. L. (1932.) The relative toxicity of rotenone and some related compounds as stomach insecticides.—J. econ. Ent., **25**, pp. 142–144.

SWINGLE, M. C. (1934.) Difference in action of derris and pyrethrum against the imported cabbage worm shown by experiments with gelatin films containing these plant materials.—J. econ. Ent., **27**, pp. 1101–1102.

TISCHLER, N. (1935.) Studies on how derris kills insects.—J. econ. Ent., **28**, pp. 215–220.

WIGGLESWORTH, V. B. (1935.) The regulation of respiration in the flea, *Xenopsylla cheopis*, Roths. (Pulicidae).—Proc. roy. Soc., (B), **118**, pp. 397–419.

——. (1941.) The effect of pyrethrum on the spiracular mechanism of insects.—Proc. R. ent. Soc. Lond., (A) **16**, pp. 11–14.

WOKE, P. A. (1938.) The biological disposition of rotenone after ingestion by the southern army worm.—J. agric. Res., **57**, pp. 707–712.

SOME PIONEER WORK ON PROTECTION AGAINST BODY LICE BY THE USE OF LASTING INSECTICIDES.

By J. R. Busvine, Ph.D., B.Sc.

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Introduction.

This paper describes part of an extensive programme of research on new methods of controlling body lice carried out during 1940-1942. The work was initiated by Professor P. A. Buxton, F.R.S., with whom the writer was privileged to collaborate, and financed by grants by the Medical Research Council. The results proved for the first time the possibility of continuous protection against body lice over a period of several weeks after treatment. To some extent, the materials and methods of achieving this have now been improved or superseded; but it has seemed worth putting on record some details of technique and the results for their scientific interest.

It was this work that led to the development of new methods of controlling the head louse (Busvine & Buxton, 1942).

The Problem.

The importance of destroying lice for quelling epidemics of typhus or trench fever has attracted considerable attention. Many adequate de-lousing procedures, adapted to field conditions, have been developed and used. Nevertheless, treatment of clothing with steam, hot air or fumigants by itself have never proved capable of effecting a lasting reduction of the general lousiness of a very large group of people living under primitive conditions. The reason for this is that it is seldom possible to segregate the treated people from the infested ones or from infested habitations. Reinfestation rapidly occurs. Effective measures would require destruction of lice plus protection from reinfestation. To achieve this, some lasting insecticide remaining on the undergarments would seem to be required. None of the chemicals used for destroying lice during the last War gave protection for more than a couple of days (Hase, 1915). The problem was, therefore, to find a suitable insecticide which was lethal to lice, innocuous to man, and stable and lasting if applied to undergarments next to the skin.

Laboratory Tests.

Most of the experiments were made with a small number of commercially available insecticides, which seemed most suitable either because of existing published data or because they seemed promising in initial tests. These were:

Lauryl thiocyanate (Lauryl rhodanate). A commercial grade of dodecyl thiocyanate made by Imperial Chemical Industries was used for many laboratory and all the field tests with this insecticide.

Lethane 384 (50 per cent. β butoxy ^{1} thiocyano diethyl ether; 50 per cent. refined kerosene).

Lethane 60 (50 per cent. thiocyanethyl laurate; 50 per cent. refined kerosene).

Lethane 384 Special (12.5 per cent. β butoxy β^{1} thiocyano diethyl ether; 37.5 per cent. thiocyanethyl laurate; 50 per cent. refined kerosene).

The Lethanes are manufactured in U.S.A. by Messrs. Röhm and Haas and marketed in Britain by Messrs. Ch. Lennig, from whom samples were obtained.

" Pyremist L " (1.3 per cent. pyrethrins in a heavy white oil). Sample obtained from Messrs. Stafford Allen.

For diluting these drugs the following two mineral oils were used:

Odourless distillate. A refined light oil slightly above the paraffin cut. S.G. .779, B.P. 200-260 degrees C., Flashpoint (closed) 71 degrees C., Viscosity; Redwood I: 32 sec., at 20 degrees C. (This oil is very similar to the refined paraffin incorporated in the " Lethanes ".)

P31 White oil. A very high boiling refined mineral oil rather similar to medicinal paraffin. S.G. .862 I.B.P. 325 degrees C., Flashpoint (closed) 180 degrees C., Viscosity; Redwood I: 141 sec., at 20 degrees C. This oil is known as Shell oil 24210 or P31.

For rapid and accurate evaluation of the toxicity of insecticides, it is necessary to test them under controlled conditions. A colony of lice was reared for this purpose on the legs of volunteers by the pill box method described by Buxton (1939). From the colony, lice were removed for precise tests which were done by two main methods—namely, spraying the lice directly with the drugs or putting the lice on to treated fabrics.

(a) Direct Spray Tests.

Adult lice were placed in glass dishes with filter paper-lined bottoms. The substances under test were dissolved to various dilutions in the oil P31. The insects were then sprayed with the solutions in the apparatus described by Potter (1941), adjusted to give an even deposit of 0.36 mg. per sq. cm. at which rate the oil diluent was completely innocuous. Lice were sprayed in batches of 10 and two or more replicates used for each concentration. After spraying they were left in the dishes overnight and then transferred to breeding boxes which were worn daily on the leg. Final mortalities were estimated after three days, and these are shown for some of the more promising insecticides in Table I.

TABLE I

Relative Toxicities of Various Drugs to Adult Lice applied by Direct Spray in Oil Solution

		Median Lethal Concentration (per cent.)
1	Octyl thiocyanate	5.0
2	Decyl thiocyanate	5.0
3	Dodecyl thiocyanate	5.0
4	Tetradecyl thiocyanate	11.0
5	Hexadecyl thiocyanate	18.0
6	Octodecyl thiocyanate	25.0
A	β Butoxy β' thiocyano diethyl ether (Lethane 384)	1.5
B	Thiocyanethyl laurate (" Lethane 60 ")	8.1
C	1 : 3 Mixture of A and B (" Lethane 384 Special ")	2.5
D	Lauryl thiocyanate	6.0
E	Bis-ethyl xanthogen	6.2
F	Benzyl benzoate	22.0
G	" Pyremist L "	34.0 (0.44 per cent. pyrethrins)
H	" Pyremist L," plus 2 per cent. isobutyl undecyleneamide	3.0 (0.04 per cent. pyrethrins)

Nos. 1 to 6: Pure compounds. (Results estimated from spraying 10 to 30 insects at three concentrations.)

Nos. A to H: Commercial preparations. (Results estimated from spraying 20 to 100 insects at four to six concentrations.)

From these results certain conclusions can be drawn as to the relative toxicity of the samples:

(i). The preliminary tests with aliphatic thiocyanates show a sudden drop in toxicity to lice in the higher members of the series. This phenomenon has been observed with other series and other insects. (See Ferguson, 1939, for explanation.) The lowest members are also especially toxic to mammals (Cameron & others, 1939). Lauryl (dodecyl) thiocyanate seems to be the most favourable compromise between toxicity to insects and safety to man.

(ii). Of the more complex thiocyanates, β butoxy β^1 thiocyano diethyl ether is much more insecticidal than thiocyanethyl laurate; but it is also more toxic to mammals (Main & Haag, 1942). The mixture "Lethane 384 Special" is another favourable compromise between insecticidal power and safety.

(iii). Bis-ethyl xanthogen has been used on a large scale in Russia for control of body lice (Soboleva, 1942). It is about as toxic as lauryl thiocyanate.

(iv). Benzyl benzoate was tested because of its known efficacy for treating scabies. It is not very toxic to body lice.

(v). The toxicity of the pyrethrins to lice is increased tenfold by admixture with 2 per cent. isobutyl undecyleneamide. The latter is not appreciably toxic at this concentration. A 4 per cent. spray produced only 7 per cent. kill.

(b) Tests with treated Cloth.

The direct spraying tests described above give the relative toxicities of the insecticides, but no information about their lasting powers or their behaviour on cloth. Two kinds of cloth were used in the experiments to investigate these points: (i) khaki flannel (a wool-cotton mixture as used in army "Angola" shirting, (ii) a rather rough calico available in large quantities.

The cloth was either sprayed with insecticide in the Potter tower or else impregnated by the use of a volatile solvent. The toxic effects of the cloth to lice were determined by putting small pieces of cloth in feeding tins with adult lice and observing the mortality caused at daily intervals.

(i) Cloth tested shortly after spraying.

Samples cut from cloth on the day of spraying required exceedingly small quantities of drug per square centimetre to be lethal to lice. Considerably more was required if the insecticide was impregnated than if it were sprayed because the material was left distributed through the thickness of the cloth instead of being concentrated on the surface (see Table II).

Table II.
Toxicity of Treated Fabric (Khaki Flannel) to Lice.

	Approximate lethal dose of active principle (mg. per sq. cm.).		
	Sprayed 50 per cent. in oil	Sprayed 10 per cent. in oil	Applied in volatile solvent
Lauryl thiocyanate	0.06	0.04	0.45
Lethane 384	—	0.02	—
Lethane Special	—	0.02	—
Pyrethrins	0.006	0.0045	0.031

The oil diluent used was P31, except for the Lethanes, which already contain kerosene, so the latter was used for further diluting them.

(*ii*). *Cloth tested after storage.*

If the sprayed fabric was stored for a week at 30° C. (the temperature of clothing next the human skin), considerably higher doses were required for the material to remain toxic. Only partial kills were obtained with doses three times the lethal doses of Table II. With slightly volatile drugs such as Lethane 384, this may have been due to evaporation. (The toxicity of more volatile drugs was lost altogether.) With the others it was probably due to the insecticide creeping away from the surface into the body of the cloth.

(*iii*) *Cloth tested after wearing.*

Sprayed fabrics were worn for various periods before examination to assess the losses due to seepage on to the skin and other garments and the possible chemical effects of sweat.

Khaki cloth was sprayed with various thiocyanates at ten times the initial lethal doses quoted in Table II and worn for three days by actively sweating men. Test pieces cut after this gave only partial kills of lice. The kills were highest when only a small quantity of diluent oil was used with the insecticides.

From these results it seemed likely that only heavy impregnations would last sufficiently long to render garments louse-proof for a suitably long time. Accordingly tests were made with calico impregnated at the rate of 1 to 3½ mgms. of active principle per square cm. and worn next the skin for several weeks.

Odourless distillate was used as a diluent at the rate of 3½ to 5 mgm. sq. cm. At these rates, the persistence of the toxicity to lice was very encouraging (see Table III).

TABLE III

Lasting Powers of Insecticides on Worn Calico.

7 mg. per sq. cm. total drug + oil	Average kills of lice by pieces of calico worn for different times			
	Worn 7–10 days	Worn 11–16 days	Worn 17–22 days	Worn 23–30 days
50 per cent. lauryl thiocyanate	100 (2)	100 (3)	100 (5)	85 (4)
50 ,, stored 3 months	100 (6)	100 (6)	69 (4)	75 (3)
25 per cent. lauryl thiocyanate	100 (5)	100 (5)	69 (3)	70 (4)
25 ,, Lethane 384	100 (2)	83 (8)	66 (6)	0 (2)
50 ,, Lethane 384 special	100 (3)	81 (5)	55 (4)	24 (2)
0.6 per cent. Pyrethrins + 5 per cent. isobutyl undecyleneamide	100 (3)	94 (4)	66 (3)	74 (2)
50 per cent. bis-ethyl xanthogen	100 (3)	67 (3)	32 (2)	0 (2)

The number of cases tested are given in brackets.

(*iv*). *Effects of washing.*

The toxic effects of all these drugs are much reduced or entirely lost by washing the treated cloth thoroughly with soap and hot water.

(c) Conclusions from Laboratory Tests.

To impregnate a whole garment at the rates given in Table III would have been impracticable for several reasons: it would have been wasteful of insecticide (most of which had to be imported), and it might have caused toxic effects to the wearer.

The most evident alternative was to treat strips of the undergarments, especially those portions (the seams) where lice were likely to congregate. Two experimentally determined facts made this method of treatment seem feasible:

(a) It was found that lice wander about very considerably under natural conditions among the underwear (Busvine, 1944). This would make it highly probable that in the course of time all the lice would come into a treated area if they were not strongly repelled by the drug.

(b) Tests made with the choice chamber described by Wigglesworth (1941) proved that lice would frequently cross from untreated cloth to a treated area without hesitation—*i.e.*, these thiocyanates do not seem to have much repellent effect.

Laboratory tests could take the matter no further, and it was necessary to try the insecticides under field conditions.

Field Trials.

The field trials were less exact but quite natural, for they were carried out on naturally infested men. Most of these men were chronically lousy tramps, and some were exceedingly heavily infested. (Some observations on the louse populations found are given in the Appendix.) In considering the results of field trials one has to remember the difficulties of the experiment. The infested men were induced to come by a payment made at each visit; but they were casual by temperament, and some of them occasionally in work. Consequently they were liable to disappear for irregular periods, and many experiments were spoilt in this way. No two of them dressed alike. They lived and slept as they pleased, and were liable to reinfestation. Once or twice there seemed to have been trafficking in lice, some men being unwilling to be freed of lice and then discharged! But on the whole they co-operated willingly. For all these reasons the results are not regular, nor ever could be under the conditions of the work. One would not attempt to draw any conclusions from them unless a large effect was observed in the average results.

The procedure in a field trial was as follows: all the man's clothes were examined for lice and a precise count made on the garment next the skin (shirt or vest). The treatment was then applied to the inner surface of this garment with special attention to the seams. The usual treatment was 8-10 cc. of insecticide in oil sprayed on with an Aerograph "MP" gun. Except where stated, no treatment was made to pants or other garments, and these constituted a reservoir for reinfesting the shirt. Moreover, the man probably associated with untreated lousy friends and perhaps lived in infested quarters. Certainly it was found that a clean shirt or one treated with a non-persistent insecticide became heavily infested within a few days.

After treatment, the man was told to continue to wear the sprayed shirt and not to wash it. (These points were checked by numbering the shirt and marking with a spot of water-soluble dye.) Subsequently he reported at intervals of 2-3 days, and the lice on the shirt were counted at different periods after treatment.

Table IV summarises the results obtained by treating one garment only. The numbers of lice in subsequent counts were expressed as percentages of the original infestation, and the figures given in the table are averages of these percentages for groups receiving the same treatment (see Table IV).

TABLE IV.

Field Trials with infested Men. Average Reductions of Infestation after various Treatments. (Only one garment treated.)

Insecticide (average 8 cc. used)	No. of cases	Average per cent. original infestation at different times after treatment (days)				
		1–3	4–6	7–10	11–16	17–22
A "Pyremist L"	12	65	53	69	—	—
B 10 per cent. isobutyl undecyleneamide	8	113	104	149	—	—
C 50 per cent. A ± 50 per cent. B	12	31	34	37	—	—
D 50 per cent. lauryl thiocyanate	8	31	20	7	14	10
E Lethane 384	13	8	8	12	39	30
F Lethane 60	4	44	33	90	—	—
G Lethane 384 special	9	4	7	21	30	—
H Lauryl-Lethane mixture	6	5	8	6	14	9

The pyrethrum series, on the whole, was disappointing. A mixture of pyrethrum and isobutyl undecyleneamide showed evidence of synergistic toxicity, but the net result was not promising.

Of the thiocyanates, Lethane 384 was most rapid in action but it was not very persistent, and it occasionally caused skin irritation. Lauryl thiocyanate was slower to take maximum effect but very lasting. Accordingly a mixture (1 part Lethane 384 to 3 parts 50 per cent. lauryl thiocyanate) of the two was tried and found to be very promising. This mixture was tried in a series of experiments in which two garments were treated. Individual results are given in Table V. It will be seen that the average percentage of infestation was brought down to 1 per cent. and kept at or close to that figure for a month at least (see Table V).

TABLE V.

Field Trials with Infested Men. Individual Records of Men with Shirt or Vest Sprayed with 8 cc. and Pants with 5 cc. of Lauryl-Lethane Mixture.

Case	Original no. of lice	Percentage of original infestation on different days after treatment						
		1–3	4–6	7–10	11–16	17–22	23–30	31–37
A	2,500	1.4	0	0	0	0.1	2.5	5.2
B	299	0.3	0	0.3	0.5	0.6	0.7	0
C	49	0	1	2.0	0	0	0	0
D	220	2.2	1	0	0	0	0	0
E	858	—	—	0.2	0.9	0.4	2.4	1.6
Average	—	0.8	0.5	0.5	0.3	0.2	1.1	1.4

The method of controlling lice by spraying undergarments with thiocyanates (Lethane 384 Special) was used on a considerable scale in a large London shelter for infested vagrants during the months of heavy air raids. The system worked well and resulted in the elimination of lice under difficult conditions. It is safe to say that intermittent visits to the cleansing station would never have cleared up the general infestation.

The "Lethane Belt."

One disadvantage of the thiocyanate treatment was early apparent; all the insecticides of this type are removed from garments by ordinary washing. To utilise their lasting effect to the full, therefore, one would have to advise against washing the clothes for a few weeks, which is unhygienic.

An alternative was to issue to infested people a supplementary impregnated garment attractive to lice, the simplest form being a kind of belt to be worn next to the skin. Several types were tested, and the cheapest efficient pattern was one specially designed by the Cotton Research Board. It was six inches wide, and could be cut to any length according to waist measurement. It is worn round the waist and secured by tags tied at the ends (fig. 1). The belt material was of calico woven in such a way that the surface was puckered into small pleats which are very attractive to lice.

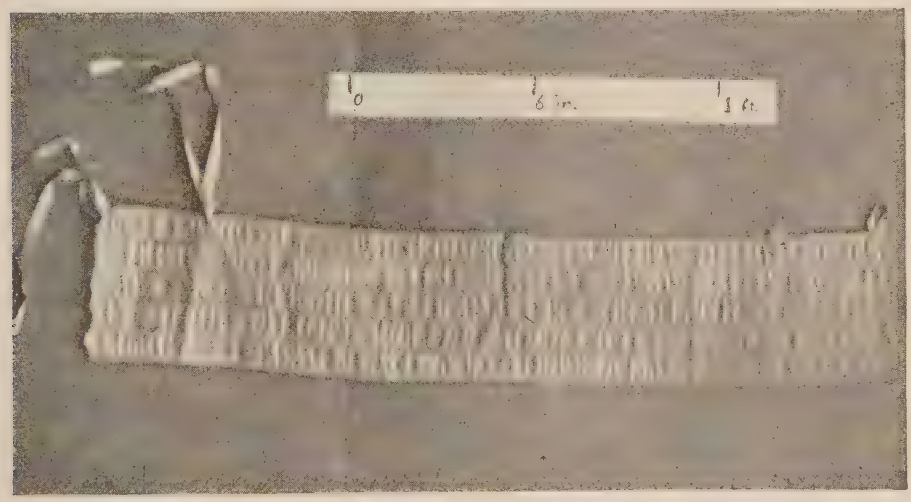

Fig. 1.—The " Lethane Belt."

If an infested man wears one of these belts, the wandering lice settle in the folds of the belt for long periods. Consequently a large proportion of the man's louse population can be found on the belt a few days after he puts it on. If the belt is previously impregnated, the lice are still attracted by it, but, after a short sojourn on it, they drop off dead. By this means one can reduce the population of an infested man and hold it low until the toxicity of the belt declines. The figures in Table III show that treated calico retains its toxic powers for several weeks.

These belts were tried out on infested tramps, and it was found that they caused a considerable and sustained reduction in lousiness (see Table VI). They were very popular among the infested men who had not experienced prolonged relief from lice for many months.

The impregnation finally adopted as most suitable on grounds of efficiency and supplies available was Lethane 384 Special, at the rate of 8 cc. per belt. The value of the " Lethane belts," as they came to be called, in a general campaign against lousiness, would be supplementary to the general de-lousing measures adopted.

TABLE VI.

FIELD TESTS WITH INFESTED MEN. REDUCTION OF INFESTATION BY WEARING A TREATED BELT. (NO OTHER TREATMENT.)

Insecticide (8 cc. per belt)	No. of cases	Percentage of original infestation on different days after putting on belt				
		1–3	4–6	7–10	11–16	17–22
50 per cent. Lauryl thiocyanate ..	4	43	25	36	21	—
50 ,, Lethane 384	5	35	18	30	40	50
25 ,, Lauryl thiocyanate ..	4	75	41	34	29	62
50 ,, Lethane Special	4	24	23	24	34	72

They can be treated in large numbers and easily transported to a group of lousy people far away. (The weight of one treated belt is about one ounce.) They can be issued rapidly and worn before and after other de-lousing treatments. They would tend to check the rapid spread of lice from heavily infested individuals before treatment and protect treated people from becoming heavily infested for a few weeks afterwards.

Limitations of the Method.

The general principle of lasting protection from lice is clearly very sound. But the thiocyanates are not entirely satisfactory for achieving this, because all of them are liable, under certain circumstances, to cause considerable irritation to the human skin. If a man wearing a treated garment or a belt within a short time after application does heavy manual work and sweats freely, these insecticides cause a severe burning sensation accompanied by erythema. This is most liable to occur with Lethane 384, and less so with Lethane 384 Special or lauryl thiocyanate. The irritation does not occur with sedentary workers, and usually subsides when the man cools down and stops sweating. No chronic toxicity has been observed, but the result of repeated heat irritation has not been investigated.

Appendix.

While the field trials were being conducted, a large number of observations on the louse populations of about 100 infested men were made. Owing to the fact that the men were induced to come for examination by payments, and that only those with more than ten lice were accepted, the samples of infested men were very biassed and unrepresentative even of infested people as a whole. Accordingly, only certain conclusions can be drawn from the data to supplement an extensive study made by MacLeod & Craufurd-Benson (1941).

A. Proportions of Men in different Infestation Groups.

1. Field trials were initiated in 1940, interrupted from time to time, and resumed after quite long intervals when further tests were required. The new cases who came in these different periods were distributed in infestation groups as follows:

No. of lice on garment next skin	Numbers of new cases				
	April and May, 1940	June and July, 1940	Nov., 1940–Feb., 1941	March–July, 1941	March–June, 1942
11–30	18	13	1	0	1
31–90	12	10	5	6	2
91–150	1	2	0	4	0
151–500	5	3	1	4	2
500–	1	1	4	4	1

It will be seen that throughout 1940 a reasonably natural distribution of new cases came for treatment. The greater numbers of low infestations are a general rule borne out by MacLeod and Craufurd-Benson's figures and by extensive data for the head louse.

In all subsequent periods there were disproportionately large numbers of high infestations.

B. *Distribution of Lice on the Undergarments.*

1. The average percentage distribution of lice at different sites was as follows:

Neckband seams	15	Arm surfaces	8
Armpit seams	11	Front surface	17
Sleeve seams	9	Back surface	18
Side seams	22		
Total seams	57	Total surfaces	43

This proportionate distribution did not differ significantly in any of the infestation classes, whether heavy or light. It will be seen that over half the lice were clustered in a very small area; along the garment seams.

2. Shirts worn next to the skin had more frequent heavy infestations than vests, probably because they are larger. There was no clear correlation of infestation with wool or cotton garments.

	Percentage of cases with					
	1–20 lice	21–80 lice	81–150 lice	151–500 lice	Over 500 lice	No. of cases counted
Cotton shirts	18	35	15	20	12	66
Woollen shirts	27	47	0	13	13	15
Cotton vests	36	46	18	0	0	11
Woollen vests	42	21	24	9	4	33

References.

BLISS, C. I. (1935.) The calculation of the dosage-mortality curve.—Ann. appl. Biol., **22**, pp. 134–167.

BUSVINE, J. R. (1944.) Simple experiments on the behaviour of body lice.—Proc. R. ent. Soc. Lond., (A) **19**, pp. 22–26.

—— & BUXTON, P. A. (1942.) A new method of controlling the head louse.—Brit. med. J., 1942, no. 4240, pp. 464–466.

BUXTON, P. A. (1939.) The Louse. London, Arnold.

CAMERON, G. R., DONIGER, C. R. & HUGHES, A. W. McK. (1939.) The toxicity of lauryl thiocyanate and n-butyl carbitol thiocyanate.—J. Path. Bact., **49**, pp. 363–379.

FERGUSON, J. (1939.) The use of chemical potentials as indices of toxicity.—Proc. roy. Soc., (B) **127**, p.387.

HASE, A. (1915). Weitere Beobachtungen über die Läuseplage.—Zbl. Bakt. (1. Abt. Orig.) **77**, pp. 153–163.

MACLEOD, J. & CRAUFURD-BENSON, H. J. (1941.) Observations on natural populations of the body louse.—Parasitology, **33**, pp. 278–299.

MAIN, R. J. & HAAG. (1942.) Toxicity of two organic thiocyanate insecticides.—Industr. Med., November.

POTTER, C. (1941.) A laboratory spraying apparatus.—Ann. appl. Biol., **28**, pp. 142–169.

SOBOLEVA, N. I. (1942.) The use of " K " preparation against pediculosis. (In Russian.)—Med. Parasitol., **10**, pp. 576–580.

WIGGLESWORTH, V. B. (1941.) The sensory physiology of the human louse. —Parasitology, **33**, pp. 67–109.

THE MOSQUITOES OF BWAMBA COUNTY, UGANDA.

II.—BITING ACTIVITY WITH SPECIAL REFERENCE TO THE INFLUENCE OF MICROCLIMATE.

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Introduction.

During 1941, field investigations on yellow fever led to the isolation of yellow fever virus from a human case and from *Aëdes (Stegomyia) simpsoni,* Theo., in Bwamba County, Western Province, Uganda (Mahaffy & others, 1942). As a result of this discovery, an intensive entomological study of the area was begun early in 1942 and is still in progress, headquarters being situated at Bundibugyo, the administrative centre of the county. Bwamba is a small area in the extreme west of Uganda, lying between the Ruwenzori Mountains and the Semliki River. It has been described in some detail in a recent paper (Haddow, 1945), to which reference should be made for a discussion of the topography and vegetation.

One of the main items in entomological work in Bwamba is the collection of large numbers of wild mosquitos in the hope of isolating yellow fever virus from them. While it seems likely that *A. simpsoni* is the main vector responsible for the occurrence of human cases, the epidemiology of the disease in Bwamba cannot be explained on the assumption that it is the only carrier. It has been postulated that the disease occurs endemically among animals in the Semliki Forest, and if this should be the case, it seems likely that the vector must be a forest mosquito or other Arthropod, as it is well known that *A. simpsoni* is largely confined to banana plantations and their immediate neighbourhood in the areas inhabited by man. Accordingly, large catches of adult mosquitos have been made both in banana plantations and in the uninhabited forest. The forest catches are being made in the hope of discovering the unknown vector of the postulated animal-to-animal cycle. The catches in banana plantations are being made to find whether or not infection is still present in *A. simpsoni.* This is regarded as a point of importance, as the entire population of Bwamba was vaccinated against yellow fever toward the end of 1941. The occurrence of yellow fever virus in *A. simpsoni* in the presence of this immune human population would be evidence pointing to the persistence of yellow fever in some non-human host.

In the course of routine catches it became apparent that there was great diversity of biting behaviour among the species encountered and that a given species often showed a tendency to bite most actively at some particular time of the day or night. It was also noted that the mosquito fauna of banana plantations and of forest consisted of entirely different groups of species, even where these habitats were actually contiguous and where conditions in both might appear very similar to the observer. Work was therefore begun to investigate the daily biting cycle of the more important species and to find the best methods of capture. In conjunction with this work, which consisted mainly of catches carried on continuously over 24-hour periods, climate observations were made in forest, in banana plantations and in the open, with the object of finding whether or not the biting behaviour of the species concerned could be explained in terms of microclimate of the habitat. The object of the present paper is to discuss the results of these investigations.

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Observations on Microclimate.

This work was based on the comparison of thermograph and hygrograph records, made simultaneously in different environments. Two thermographs and two hygrographs were available. Before beginning field observations, the instruments were exposed side by side in the laboratory at Bundibugyo. Comparison of the traces showed that the pairs of instruments were closely comparable. During this preliminary test calibration was also carried out. In the case of the thermographs this was done by leaving a thermometer with its bulb beside the coil of each instrument, while in the case of the hygrographs the readings were repeatedly checked by means of a whirling hygrometer. In the field the pairs of instruments were exposed in identical Stevenson screens, the bases of the screens being three feet from the ground. In no case were the screens more than 300 yards apart, as, in the area concerned, climatic incidents such as showers and gusts of wind are often extremely local and the comparison of traces, made some distance apart, might lead to serious fallacies in interpretation.

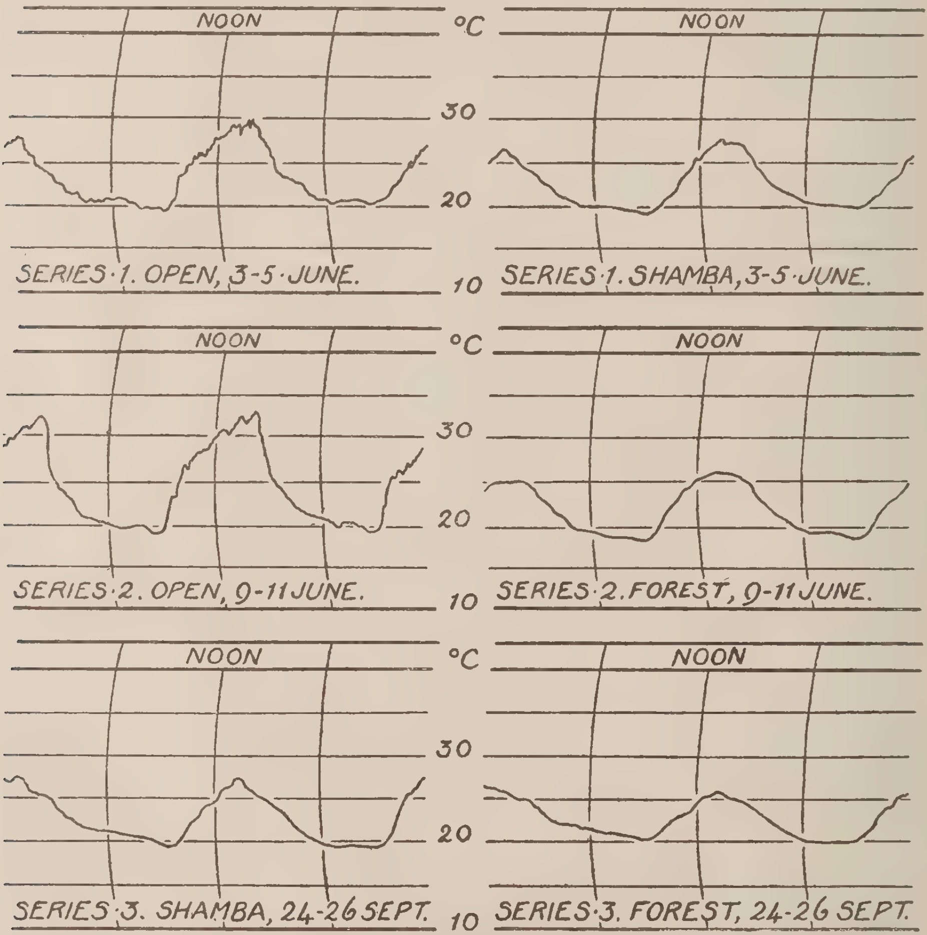

Fig. 1.—Parts of actual thermograph records, showing comparisons of temperature between a banana plantation (shamba) and the open air (Series 1), primeval rain forest and the open air (Series 2) and primeval forest and a banana plantation (Series 3).

Light observations were also made. The only photometer available was a photoelectric cell with a scale graduated in arbitrary units which it has not been possible, at the moment, to calibrate in terms of foot-candles. While the readings have no value as absolute figures, it is felt that they present a fairly satisfactory comparison between the conditions in the various environments. In making observations, an inverted bowl was placed on a stake three feet high and was covered with a white cloth, which provided a standard dazzle-free surface. The reading was taken at a distance of six inches from the most brightly illuminated side, the axis of the photometer being perpendicular to the surface of the bowl. The photometer was thus always directed slightly downward and fallacies due to the entry of sky light were avoided. Readings were made at clock hours. Unfortunately, it was not possible to make the light readings at the same time as the temperature and humidity observations.

It was found convenient to use the 24-hour clock. As climate readings and mosquito catches were both based on an hourly programme, minutes need not be allowed for and it is unnecessary to quote four figures for a time reading. Thus 2 A.M. is referred to as 02 hours and 2 P.M. as 14 hours. At the beginning of a 24-hour observation period midnight is referred to as 00 hours and at the end of the period as 24 hours. Local Mean Time (L.M.T.) has been used throughout. As the centre of Bwamba lies 30^0 east of Greenwich, this may be taken as two hours ahead of Greenwich Mean Time.

Temperature readings are correct to 0.5^0 C., and relative humidity to the nearest whole number per cent. Saturation deficiency figures are based on data given in the official German Assmann tables (1937) and are correct to 0.5 mm. While the light readings are mere arbitrary numbers, some idea of the midday light intensity in the open at ground level may be gained from the writer's records (1943), made at Kisumu, Kenya, where the highest reading was 9,300 foot-candles. As both Kisumu and Bwamba lie at about the same altitude and within one-half degree of the equator, and as both sets of readings were made about the time of the autumnal equinox, it is felt that maxima for the two areas should be at least roughly comparable.

If three sets of instruments had been available, a single comparison between forest, banana plantation and the open air could have been made. As it was, three comparisons were necessary, banana plantation and open air, forest and open air, forest and banana plantation. The results will now be discussed.

SERIES 1. *Comparison between the climate in a banana plantation and in the open.*

This comparison was carried out during a week of June, 1943. The open-air unit was placed in an exposed situation in the compound of the Yellow Fever Field Station at Bundibugyo. The other was set up in the middle of a banana plantation between 250 and 300 yards from the first. The plantation consisted of a mixture of two types of bananas ('' gonja '' and '' matoke '') of all sizes, with abundant *Colocasia* plants and some pineapples. The undergrowth was moderately dense and consisted of short grass, nettles, vines and *Ipomoea* sp. The plantation might be described as '' typical,'' *i.e.*, it did not consist entirely of one type of banana or of plants all equal in size. It had not been cleared recently, but was only moderately overgrown. In such a plantation, *A. simpsoni* is taken biting mainly around the edges and in the more open parts, while a few forest species usually occur in the densest areas.

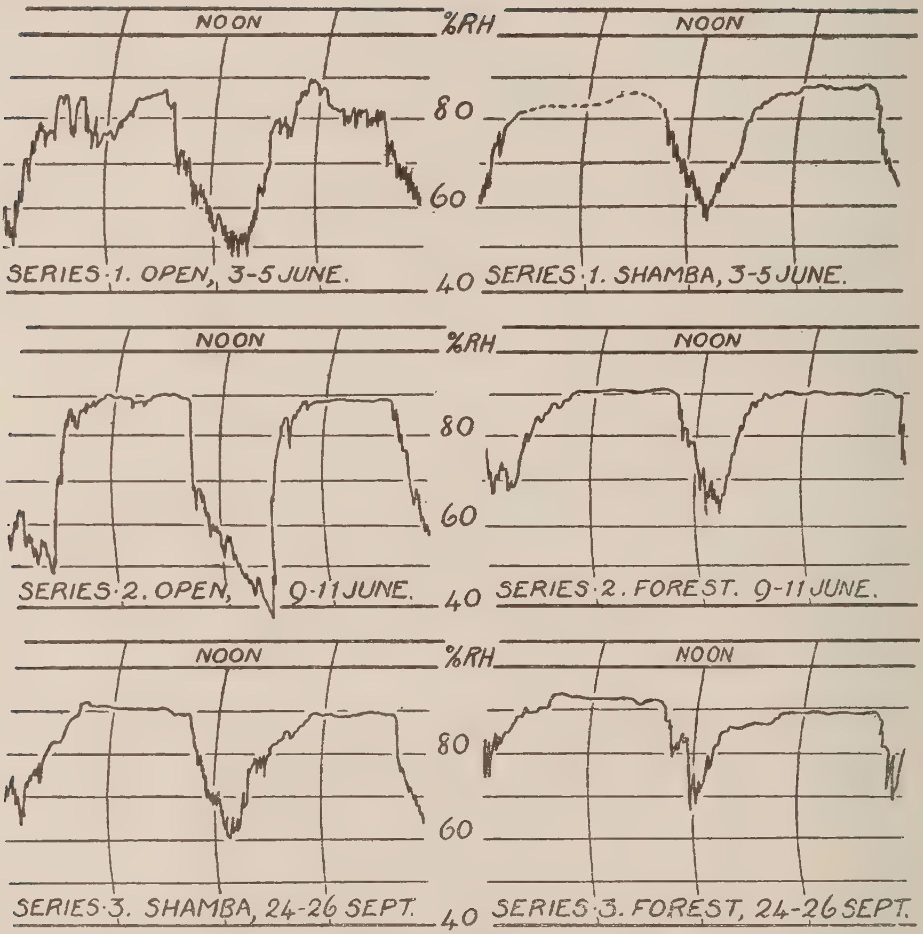

FIG. 2.—Parts of actual hygrograph records, showing comparisons of relative humidity between a banana plantation (shamba) and the open air (Series 1), primeval rain forest and the open air (Series 2), and primeval forest and a banana plantation (Series 3). The defect in the trace from the plantation in Series 1 was caused by sinking of the ground under the screen, which allowed the pen to swing free from the recording drum.

TABLE I.

Comparison between the Climate in a Banana Plantation and the Climate in the Open Air. (Series I)

Hour	Temp., °C.		R.H., per cent.		S.D., mm.		Light	
	Open	Plant.	Open	Plant.	Open	Plant.	Open	Plant.
0	21.0	20.5	81	88	3.5	2.0	1	1
1	21.0	20.0	81	88	3.5	2.0	1	1
2	20.5	20.0	82	88	3.5	2.0	1	1
3	20.0	20.0	85	88	2.5	2.0	1	1
4	20.0	20.0	84	88	3.0	2.0	1	1
5	20.5	19.5	86	88	2.5	2.0	16	8
6	21.0	19.5	84	88	3.0	2.0	116	43
7	22.0	21.0	84	88	3.5	2.5	175	107
8	23.5	21.5	82	87	3.0	2.5	193	122
9	24.5	22.5	78	82	5.0	4.0	199	127
10	25.5	23.5	71	78	7.5	5.0	201	136
11	25.5	25.0	70	74	7.5	6.5	207	175
12	26.5	25.5	63	70	10.0	7.5	200	160
13	27.5	26.0	63	70	10.5	7.5	203	157
14	27.5	26.0	62	70	11.0	8.0	205	159
15	27.5	26.0	62	71	11.0	7.5	197	143
16	27.0	25.5	66	77	9.5	5.5	186	95
17	25.5	24.5	70	79	7.5	5.0	149	66
18	23.5	23.5	79	82	4.5	4.0	62	31
19	22.0	22.0	81	84	4.0	3.0	17	0
20	21.5	22.0	78	85	4.5	3.0	0	0
21	21.0	21.0	82	87	3.5	2.5	1	0
22	21.5	21.0	79	87	4.0	2.5	1	0
23	21.0	20.5	82	88	3.5	2.5	1	0
24	21.0	20.5	81	88	3.5	2.0	1	0

Temp.—Hourly means from thermograph records.
R.H.—Hourly means from hygrograph records.
S.D.—Hourly means calculated from thermograph and hygrograph records.
Light.—Hourly means from photometer readings.

Main Comparative Figures :—

	Temp.		R.H.		S. Deficit		Light Units	
	Open	Plant.	Open	Plant.	Open	Plant.	Open	Plant.
Absolute maximum	30.0	28.0	93	90	17.0	10.5	220	212
,, minimum	18.0	18.0	46	61	1.0	2.0	0	0
,, range . .	12.0	10.0	47	29	16.0	8.5	220	212
Mean maximum . .	27.5	26.0	86	88	11.0	8.0	207	175
,, minimum . .	20.0	19.5	62	70	2.5	2.0	0	0
,, range . .	7.5	6.5	24	18	8.5	6.0	207	175

Temperature in the plantation did not show marked difference from that in the open. It was consistently lower by day, but by night the differences were insignificant (Table 1 and fig. 3). Maxima occurred in both situations at the same time (13 to 15 hours), but in the case of minima the plantation showed a distinct lag. In the open, minima occurred at 03 to 04 hours, in the plantation not till 05 to 06 hours. Though the actual differences in temperature were never great, there was a considerable difference in the duration of the daily warm period in the two areas. Taking 25^0 C. as a comparative level, it was found that in the open this temperature was exceeded for a mean of about eight hours daily, while in the plantation the corresponding period was less than six hours per day. The numerous short-duration

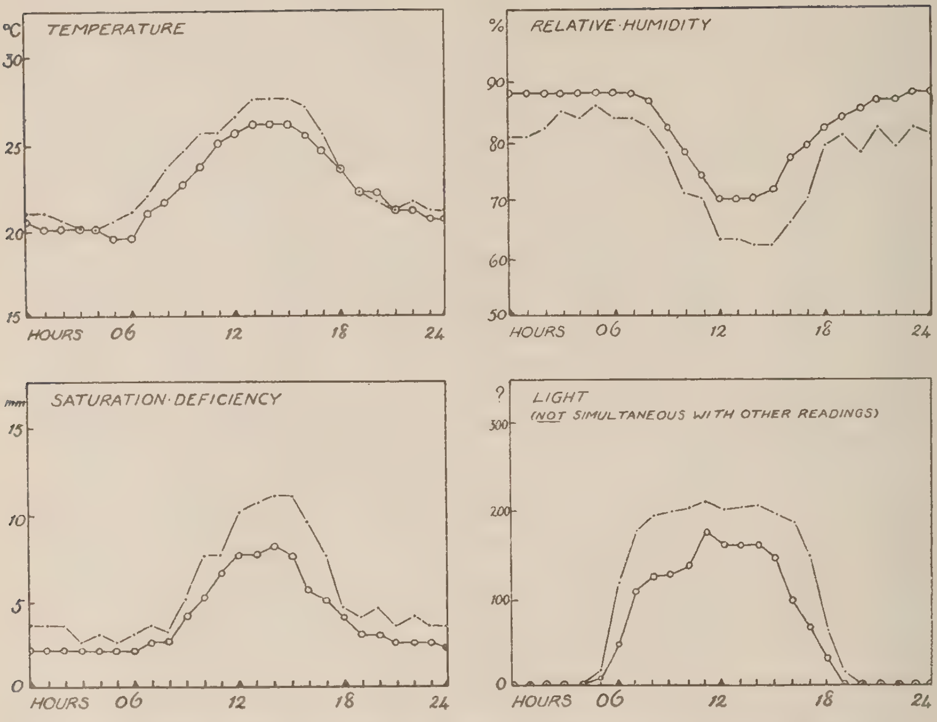

Fig. 3.—Comparison between the climate in a banana plantation and in the open air (Series 1). Data from Table I. Plantation—circles. Open air—dots.

fluctuations shown on the open-air record (caused by passing clouds, puffs of wind, etc.) were almost absent from the plantation trace, though all major peaks and depressions were clearly recognisable in both. In the open these sudden fluctuations were often quite considerable, rises or falls of as much as 20° C. being quite common (fig. 1).

In the case of relative humidity (hereafter referred to as R.H.), the plantation showed at all times a degree of saturation greater than that of the open air. An obvious difference exists between the form of daily curves for the two areas, for, while the daily fall of R.H. began in the open at 05 hours, it did not begin in the plantation till 07 hours. Further, in the plantation, the minimum was reached at 12 to 14 hours, after which the rise was rapid, while in the open the minimum was not reached till 14 to 15 hours. An interesting feature was the equability of the R.H. in the plantation by night, an even " plateau " of high saturation being maintained from 23 to 07 hours. By day the duration of the dry period was much greater in the open than in the plantation. Taking 70 per cent. as a comparative level, it was found that in the open R.H. fell below this figure for a mean of about six hours daily, while in the plantation the R.H. fell to 70 per cent. for only two hours per day. As in the case of temperature, minor short-duration fluctuations were abundant in the open-air record, sudden changes of as much as 10 per cent. being quite common, while in the plantation they were less obvious (fig. 2). It should be noted that there was a fairly large difference between the mean daily ranges of the two environments (18 per cent. in the plantation and 24 per cent. in the open).

The combination of lower temperature and higher R.H. in the plantation, as compared to the open air, was responsible for fairly marked differences between the saturation deficiency (hereafter referred to as S.D.) curves for the two areas. Once again the greatest divergence occurred during the afternoon, while by night the differences were small and probably not significant. Taking 7.0 mm. as a level for comparison, it was found that in the open this figure was exceeded for a mean of about seven hours per day, in the plantation for only about three hours per day. During the whole week, S.D. in the plantation only once exceeded 10.0 mm. to attain an absolute maximum of 10.5 mm., while in the open the 10.0 mm. level was exceeded every day and the absolute maximum was 17.0 mm. As in the case of R.H., there was marked stability of S.D. in both areas during the night. It should be remembered that the S.D., which gives a reliable index of the drying power of the air, is perhaps the most important single climatic factor influencing insect behaviour. While the highest deficiencies recorded in the open in this series were not of the order which may be considered as immediately dangerous to insect life, it was concluded that the quite considerable differences existing between the plantation and the open during the afternoon might have a marked influence on the behaviour of a mosquito, which, under favourable circumstances, moves freely from the one environment to the other.

Light records are based on a series of hourly observations carried on continuously for 96 hours. The peculiar flat-topped form of the curves is due to the fact that while each morning was clear and sunny, the afternoons were dull and cloudy, with showers. The small figures recorded for the night hours were due to diffuse moonlight. A striking point is that by 07 hours the light in the open had already reached a level as high as the daily maximum for the plantation.

SERIES 2. *Comparison between the climate in primeval rain forest and in the open.*

The comparison was carried out during a week of June, 1943, the area selected being Kanyamwerima, which lies on the main road three miles north of Bundibugyo. The open-air unit was erected in the middle of a large cleared space in the Public Works Department road camp. The other was set up in dense forest about 300 yards away. In this area the forest trees form a closed but rather thin canopy at an average height of 60 to 70 feet. Undergrowth is heavy and forms an understorey at a height of 8 to 12 feet. The actual forest floor is carpeted with dead leaves and is devoid of minor vegetation in most parts. The trees support an epiphytic growth of vines, lianas, ferns and a few orchids. This forest area has been used in making large-scale day and night mosquito catches, and is known to support a large and varied Culicine fauna.

The difference between the temperature in forest and in the open was very pronounced, much more so than in the case of the previous series. This was particularly interesting, as the week concerned was brighter and warmer than that during which Series 1 observations were made. Thus, though the open-air readings of the present series showed higher temperatures than did those of Series 1, the forest temperatures were lower than those previously obtained in the banana plantation. Temperature in the forest was consistently lower than that in the open, both by day

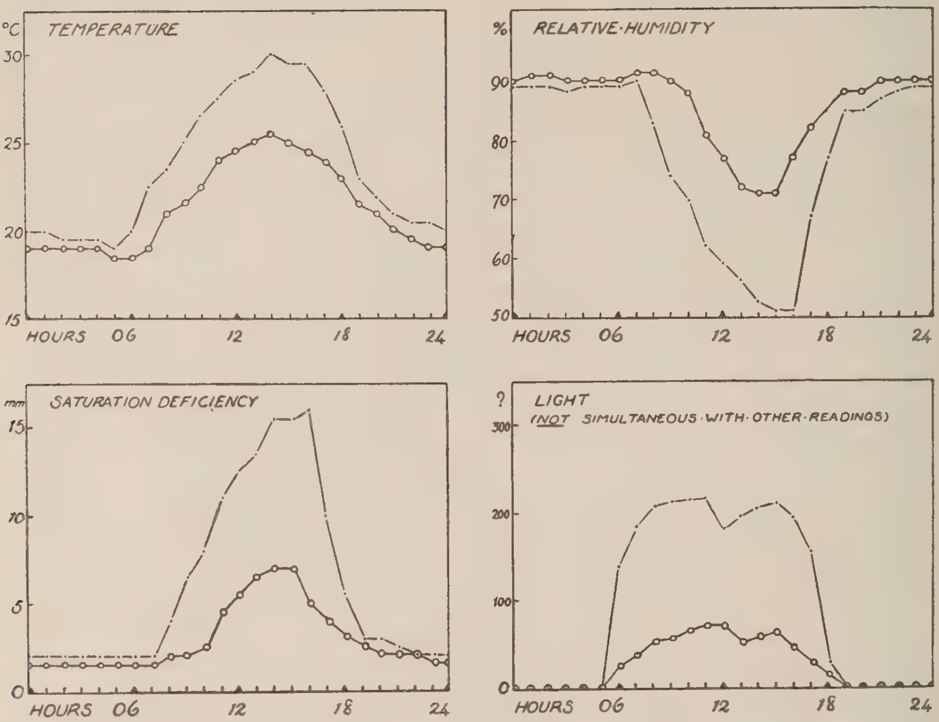

Fig. 4.—Comparison between the climate in primeval rain forest and in the open air (Series 2). Data from Table II. Forest—circles. Open air—dots.

and by night, but though the daytime differences were sometimes as much as 4 to 6° C., the differences by night were always small (Table II & fig. 4). Daily maxima occurred in both areas at 14 hours (at which time a considerable difference was obvious), but in the forest, as in the banana plantation, minima showed a distinct lag. Thus, in the open, the daily rise of temperature began at 05 hours, while in the forest little change was apparent till 07 hours. Once again there was a considerable difference between the duration of the daily warm period in the two areas. Taking 25° C. as a comparative level, it was found that in the open a higher temperature was maintained for a mean of about nine hours daily, while in forest the corresponding period was only two hours. As in the case of Series 1, the open-air record showed numerous minor fluctuations which were almost absent from the forest trace (fig. 1). The coolness and equability of the forest were very pronounced. The mean range was only 7° C., as opposed to 11° C. in the open, and the highest recorded temperature was only 26° C., as opposed to 32° C. in the open.

Throughout the week the forest consistently maintained a higher R.H. than did the open-air. By night the differences were small, and both units showed an even plateau of high humidity in the region of 90 per cent. By day the differences were considerable. As in the case of Series 1, the daily fall in R.H. began first in the open (at 07 hours), while the forest maintained its high night level till midmorning,

TABLE II.

Comparison between the Climate in Forest and the Climate in the Open Air. (Series 2.)

Hour	Temp., °C.		R.H., per cent.		S.D., mm.		Light	
	Open	Forest	Open	Forest	Open	Forest	Open	Forest
0	20.0	19.0	89	90	2.0	1.5	1	0
1	20.0	19.0	89	91	2.0	1.5	0	0
2	19.5	19.0	89	91	2.0	1.5	0	0
3	19.5	19.0	88	90	2.0	1.5	0	0
4	19.5	19.0	89	90	2.0	1.5	0	0
5	19.0	18.5	89	90	2.0	1.5	1	0
6	20.0	18.5	89	90	2.0	1.5	140	27
7	22.5	19.0	90	91	2.0	1.5	185	39
8	23.5	21.0	83	91	4.0	2.0	208	52
9	25.0	21.5	74	90	6.5	2.0	212	58
10	26.5	22.5	70	88	8.0	2.5	215	66
11	27.5	24.0	62	81	11.0	4.5	219	70
12	28.5	24.5	59	77	12.5	5.5	180	70
13	29.0	25.0	56	72	13.5	6.5	196	52
14	30.0	25.5	52	71	15.5	7.0	203	59
15	29.5	25.0	51	71	15.5	7.0	210	64
16	29.5	24.5	51	77	16.0	5.0	195	47
17	28.0	24.0	67	82	10.0	4.0	155	30
18	26.0	23.0	77	86	5.5	3.0	31	17
19	23.0	21.5	85	88	3.0	2.5	1	0
20	22.0	21.0	85	88	3.0	2.0	1	0
21	21.0	20.0	87	90	2.5	2.0	1	0
22	20.5	19.5	88	90	2.0	2.0	2	0
23	20.5	19.0	89	90	2.0	1.5	2	0
24	20.0	19.0	89	90	2.0	1.5	1	0

Temp.—Hourly means from thermograph records.
R.H.—Hourly means from hygrograph records.
S.D.—Hourly means calculated from thermograph and hygrograph records.
Light.—Hourly means from photometer readings.

Main Comparative Figures :—

	Temp.		R.H.		S.D.		Light Units	
	Open	Forest	Open	Forest	Open	Forest	Open	Forest
Absolute maximum	33.0	26.0	90	91	23.5	8.5	222	109
,, minimum	18.0	17.0	37	64	1.5	1.0	0	0
,, range . .	15.0	9.0	53	27	22.0	7.5	222	109
Mean maximum . .	30.0	25.5	90	91	16.0	7.0	219	70
,, minimum . .	19.0	18.5	51	71	2.0	1.5	0	0
,, range . .	11.0	7.0	39	20	14.0	5.5	219	70

showing little change till ten hours. In the forest the minimum was reached at 14 to 15 hours, after which a rapid rise occurred, while in the open the minimum was not reached till 15 to 16 hours. Taking 70 per cent. as a comparative level, it was found that in the open, lower humidities occurred during a mean period of about seven hours daily, while in the forest the mean R.H. did not fall as low as 70 per cent. Thus, while maxima in both areas were essentially the same, great differences were noted in the case of minima and ranges. The absolute minimum in forest was 64 per cent., while in the open it was 37 per cent., about half the forest figure, and a similar relationship was found in the case of the mean minima, which were

71 per cent. and 51 per cent. respectively. The forest minimum of 71 per cent. must be regarded as very high for a mean figure. In the case of ranges, the forest absolute range of 27 per cent. was only about half that of the open air, 53 per cent. The same relationship was found to occur in the case of the mean ranges, which were 20 and 39 per cent. respectively. As in the case of other observations, it was found that the minor fluctuations of the open-air trace were poorly marked in the forest (fig. 2).

As might be expected from the above results, considerable differences were found to exist between the S.D. curves for the two environments. By night the differences were trivial, and both areas showed a very low and stable S.D. of only 2.0 to 3.0 mm., but in the open a sharp rise began at 07 hours, while the forest showed very little change till ten hours. In the forest the maximum was attained at 14 to 15 hours, and by 16 hours (at which time the open-air maximum was reached) it had fallen considerably. Taking 7.0 mm. as a comparative level, it was found that in the open a deficiency above this level was maintained for over eight hours daily, while in the forest a figure of 7.0 mm. was reached for a mean daily period of only one hour. Large differences were found to exist between the maxima and ranges of the two environments. Thus, in the open the absolute maximum was 23.5 mm., a fairly high figure, while in the forest the highest recorded S.D. (8.5 mm.) was only about a third of this. Again the open-air mean maximum was 16.0 mm., more than twice the forest mean of 7.0 mm. In the case of ranges both the absolute and mean figures for the open air (22.0 and 14.0 mm. respectively) were approximately three times as great as the corresponding forest figures of 7.5 and 5.5 mm.

Light observations were made hourly for 96 hours. The saddleback form of the curves (fig. 4) was caused by the occurrence of clouds and showers in the early afternoons. Moonlight was just readable in the open, but not in the forest. It should be noted that by 06 hours the open-air light readings were already twice as high as the forest day maxima, and that the open-air mean maximum was more than three times as great as the corresponding forest figure.

In general, it may be said that the climate conditions found in the forest showed an equability quite remarkable in a natural environment. Further, the forest climate was of a type not likely to endanger mosquito life at any time or lead to inactivity enforced by heat or dryness. Thus the temperature never exceeded 26^0 C., R.H. never fell below 64 per cent., S.D. never rose above 8.5 mm., and the maximum light intensity was only 32 per cent. of the maximum in the open.

SERIES 3. *Comparison between the climate in primeval rain forest and in a banana plantation.*

This series of observations was made during a week of September, 1943. The forest unit was set up in the same place as in Series 2. The banana plantation unit was placed in a fairly dense plantation, with light undergrowth, about 50 yards from the spot used for the open-air observations of Series 2. Once again, the units were about 300 yards apart.

TABLE III.

Comparison between the Climate in Forest and the Climate in a Banana Plantation. (Series 3.)

Hour	Temp., °C.		R.H., per cent.		S.D., mm		Light	
	Plant.	Forest	Plant.	Forest	Plant.	Forest	Plant.	Forest
0	19.0	20.0	88	90	2.0	2.0	1	0
1	18.5	19.5	88	90	2.0	1.5	1	0
2	18.5	19.5	89	90	2.0	1.5	1	0
3	18.5	19.0	89	90	2.0	1.5	1	0
4	18.0	19.0	89	90	1.5	1.5	1	0
5	17.5	19.0	89	90	1.5	1.5	1	0
6	18.0	19.5	90	90	1.5	1.5	47	11
7	18.5	20.5	90	90	1.5	1.5	91	31
8	20.5	21.5	88	90	2.0	2.0	100	38
9	22.5	23.0	78	87	4.0	2.5	118	35
10	24.5	24.0	70	83	7.0	4.0	127	43
11	25.5	25.0	65	78	8.5	5.5	166	40
12	26.5	25.0	64	78	9.5	5.5	174	38
13	26.5	25.0	68	80	8.5	5.0	154	35
14	26.0	25.0	72	83	7.5	4.0	161	40
15	25.0	24.5	77	86	6.0	3.5	140	40
16	25.0	24.0	80	87	5.0	3.0	82	36
17	24.5	23.5	81	87	4.5	3.0	75	26
18	23.5	22.5	82	88	3.5	2.5	36	21
19	22.5	22.0	86	88	3.0	2.5	0	0
20	21.5	21.5	87	89	2.5	2.0	0	0
21	20.5	21.0	88	89	2.0	2.0	0	0
22	20.0	20.5	88	90	2.0	2.0	0	0
23	19.5	20.0	88	90	2.0	2.0	0	0
24	19.0	20.0	88	90	2.0	2.0	1	0

Temp.—Hourly means from thermograph records.
R.H.—Hourly means from hygrograph records.
S.D.—Hourly means calculated from thermograph and hygrograph records.
Light.—Hourly means from photometer readings.

Main Comparative Figures :—

	Temp.		R.H.		S.D.		Light Units	
	Plant.	Forest	Plant.	Forest	Plant.	Forest	Plant.	Forest
Absolute maximum	29.0	26.0	92	94	13.0	7.5	186	45
,, minimum	16.0	17.0	54	68	1.5	1.0	0	0
,, range ..	13.0	9.0	38	26	11.5	6.5	186	45
Mean maximum ..	26.5	25.0	90	90	9.5	5.5	174	43
,, minimum ..	17.5	19.0	64	78	1.5	1.5	0	0
,, range ..	9.0	6.0	26	12	8.0	4.0	174	43

In the case of temperature, differences between the forest and the plantation were never great. The most interesting point was that while the forest was cooler than the plantation by day, it was warmer by night (Table III & fig. 5). A similar relationship was noted by the writer in Kenya (1942) during a comparison between the climate of a native hut and that of the open air. Once more taking 25° C. as a level for comparison, it was found that in the plantation this temperature was exceeded for over six hours daily, while in the forest the corresponding period was only about three hours. Sudden minor fluctuations were not prominent in either trace, but such as were apparent were more pronounced in the plantation than in the forest (fig. 1).

The comparison between the R.H. of the two areas showed quite marked differences in the form of the curves. By night both maintained a level plateau of high humidity in the neighbourhood of 90 per cent. the differences being small and insignificant. R.H. in the plantation began to fall at 07 hours, but in the forest not till 08 hours. The greatest differences occurred at 12 hours, when minima were reached in both areas. After this time both curves showed a steady rise to the high night level. The short midday period of low R.H. was mainly responsible for the fact that the mean range in the plantation (26 per cent.) was more than twice that in the forest (12 per cent.). Minima also showed a considerable difference, the mean figure for the forest being the very high one of 78 per cent., and that for the plantation being 64 per cent. Taking 70 per cent. as a comparative level, it was found that in the plantation lower humidities occurred for a mean period of over three hours daily, while in the forest the mean R.H. did not fall as low as 70 per cent. Minor fluctuations were poorly marked on both traces (fig. 2).

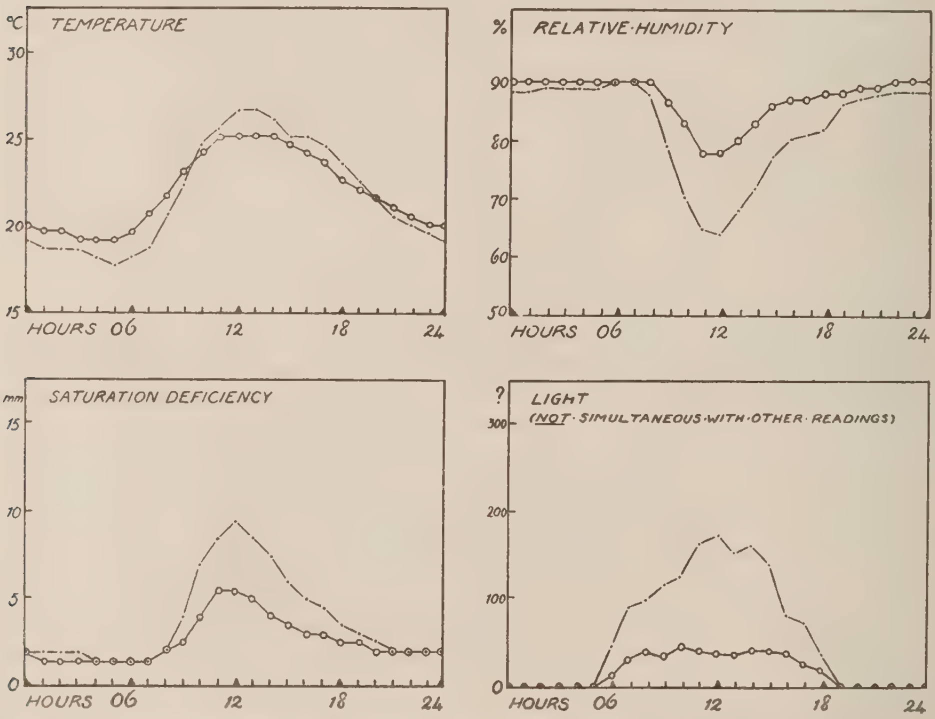

FIG. 5.—Comparison between the climate in primeval rain forest and in a banana plantation (Series 3). Data from Table III. Forest—circles. Plantation—dots.

In the case of S.D., differences during the night and most of the morning were slight or absent. The daily rise began in both areas at 07 hours, and the daily fall at 12 hours. Only during the midday period was there any marked difference, and the figures obtained at this time accounted for most of the disparity between the mean ranges, which were 8.0 mm. in the plantation and 4.0 mm. in the forest. Taking 7.0 mm. as a comparative level, it was found that this figure was exceeded for a mean of over four hours daily in the plantation, while in the forest the mean maximum was under 7.0 mm. and the absolute maximum was only 7.5 mm.

Hourly light readings were made over a period of 48 hours at Bubukwanga, on the main road, five miles north of Bundibugyo. The readings from the plantation agreed quite closely with those of Series 1, but the forest figures were lower than the corresponding results for Series 2, on account of the fact that the forest canopy is denser at Bubukwanga than at Kanyamwerima. Once again, afternoon showers led to rather flattened saddleback curves. The main point of interest was that by 06 hours the light intensity in the plantation was already greater than the maximum attained in the forest.

General Discussion of Climate Records.

In a consideration of the above results, the main points to be noted are as follows:

By day the climate in the open shows rather low R.H., fairly high temperature and S.D. and intense light. In a banana plantation the R.H. is distinctly higher, temperature and S.D. are lower and light less intense. In forest R.H. is very high, temperature and S.D. are very low, and light is much less intense. The duration of the diurnal warm dry period is much greater in the open than in a plantation and greater in a plantation than in forest.

By night all three environments show great similarity in climate, with high and very stable R.H., low and stable S.D. and slowly falling temperature. This similarity of climate by night is of importance; it will be shown below that it affects mosquito behaviour. Table IV emphasises the wide divergence of the three microclimates by day and their close similarity by night.

Table IV.

Day and Night Means in Forest and Banana Plantations.

		Day	Night
Temperature, °C.	Open air	26.5	20.5
	Plantation ..	24.0	20.0
	Forest	23.5	19.5
Relative humidity, per cent. ..	Open air	68.0	85.0
	Plantation ..	77.0	88.0
	Forest	83.0	90.0
Saturation deficiency, mm. ..	Open air	8.5	3.0
	Plantation ..	5.5	2.0
	Forest	4.0	2.0

For purposes of this table, the means of all readings in forest and of all readings in plantations have been included to increase the size of the sample.

The next point to be noted concerns the period after sunrise. In the open all climatic factors change rapidly at this time, light, temperature and S.D. rise and R.H. falls. In banana plantations and forest, on the other hand, though light immediately begins to increase, temperature, R.H. and S.D. all show a marked lag and for some time approximate to night conditions. It will be shown that this also has an effect on the behaviour of some species.

The last point is that in the case of all four factors, temperature, R.H., and S.D. and light, the open air shows a much greater daily range than does a banana plantation and the plantation, in turn, shows a greater range than forest, which at all times is remarkably equable. Further, in traces taken on recording instruments in the open, numerous minor short-duration fluctuations are apparent. These are much less obvious in traces taken in a banana plantation, and in forest they are almost absent.

Analysis of Climate Records by Four-hour Periods.

In working out the figures for 24-hour catches of biting mosquitos, it was found best to divide the 24 hours into six four-hour periods. Various groupings (one-, three-, four- and six-hour) were tried, but the four-hour groups proved to be the most satisfactory and accorded best with the behaviour of most species. Various starting points for graphs were also tried. In practice, the catches were begun at 06 hours and this time was found, after analysis of the figures, to be the best starting point for the consideration of the 24-hour biting cycle.

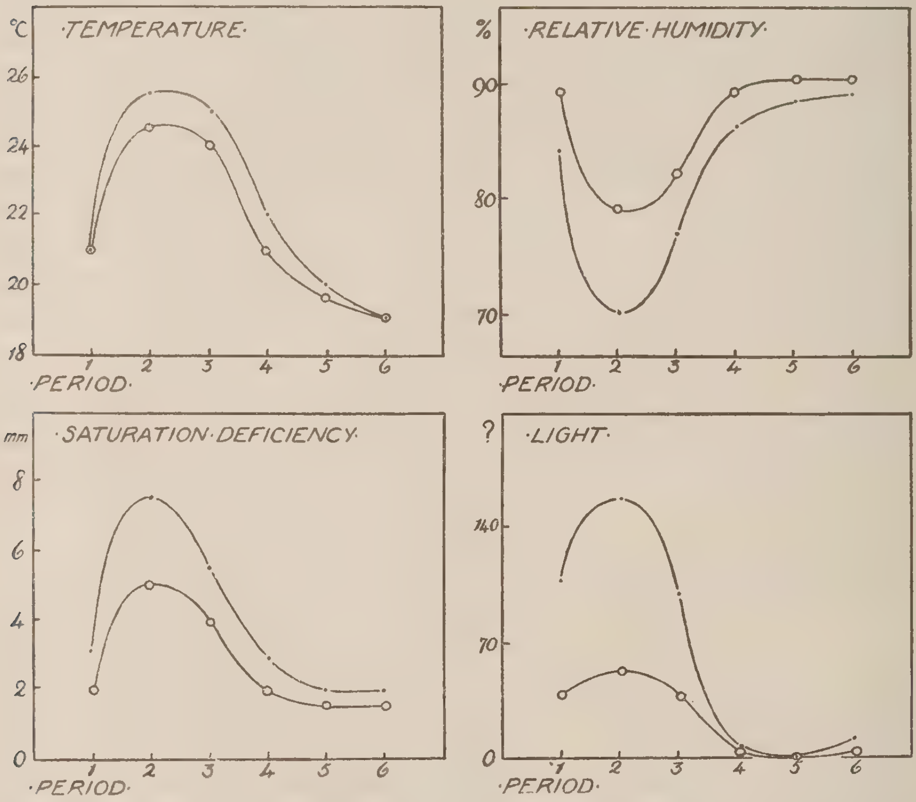

Fig. 6.—The climate of forest (circles) and banana plantations (dots) by four-hour periods. Data from Table V. The figures are means of both series from forest and both series from plantations, in order to give the largest sample available.

If climate observations are similarly grouped into four-hour periods, it is found that they agree quite well with the more detailed records and that the four-hour means show the main features of the hourly curves without undue distortion (Table V & fig. 6). As all the mosquito catches concerned were made in forest and in banana plantations, it is not necessary to discuss the open-air figures in this section. In the foregoing detailed discussion of climate, midnight was chosen as the most convenient starting point for the records, but in the present instance it is necessary to begin the graphs with the 06 to 10 hours' period (Period 1), in order to allow direct comparison with the mosquito figures.

TABLE V.

Four-hourly Mean Climate Readings in Forest and Banana Plantations.

Time (24-hour clock).		06–10	10–14	14–18	18–22	22–02	02–06
Temperature, °C.	Forest ..	21.0	24.5	24.0	21.0	19.5	19.0
	Plantation ..	21.0	25.5	25.0	22.0	20.0	19.0
Relative humidity, per cent. ..	Forest ..	89.0	79.0	82.0	89.0	90.0	90.0
	Plantation ..	84.0	70.0	77.0	86.0	88.0	89.0
Saturation deficiency, mm. ..	Forest ..	2.0	5.0	4.0	2.0	1.5	1.5
	Plantation ..	3.0	7.5	5.5	3.0	2.0	2.0
Light arbitrary units	Forest ..	40.0	51.0	38.0	4.0	0.0	4.0
	Plantation ..	107.0	157.0	99.0	6.0	0.0	11.0

For purposes of this table, the means of all readings in forest and of all readings in plantations have been included in order to increase the size of the sample.

While a four-hour grouping inevitably sacrifices detail, it brings out certain characteristics less easily recognised in detailed records. The most important point is that no two of the six periods have the same climatic features, a fact that helps to elucidate mosquito behaviour. Further, as the figures for forest and banana plantations show the same general trend, their differences being merely of a degree, the following notes are applicable to either environment. Taking the periods in turn, the following characteristics are found:

Period 1. 06 *to* 10 *hours.* *Sunrise and morning.*

This period, which follows sunrise, shows very high R.H., low temperature and S.D. and low light intensity.

Period 2. 10 *to* 14 *hours.* *Middle day.*

All the extremes occur in this period. R.H. is at its minimum, and temperature S.D. and light are at their maximum.

Period 3. 14 *to* 18 *hours.* *Afternoon and evening.*

This period shows low R.H. and fairly high temperature, and S.D. light intensity is low.

Period 4. 18 *to* 22 *hours.* *Sunset and early night.*

This period is characterised by very high R.H., rather low temperature and very low S.D. Readable light is confined to a short period just after sunset.

Period 5. 22 *to* 02 *hours.* *Middle night.*

During this period R.H. is very high, temperature is lower than in Period 4, S.D. is very low, and light, for practical purposes, is nil.

Period 6. 02 *to* 06 *hours.* *Late night and dawn.*

In this period R.H. remains very high, temperature is about its minimum and S.D. is very low. Readable light appears sometime before sunrise, which concludes the period.

These characteristics are summarised in Table VI.

Using this four-hour basis, it is possible to discuss the behaviour of certain mosquitos from a climatic standpoint. One of the most useful points to note is the fact that throughout the night R.H. and S.D. are very stable and light is practically nil, while the steadily falling temperature forms the main variable. Thus, if a given species begins biting just after dark, rapidly reaches its peak activity and then decreases gradually till sunrise, it seems reasonable to argue that R.H. and S.D. are not likely to be controlling factors, as they hardly change during the whole period concerned. It might be concluded that such a species bites in darkness, that its activity is at a maximum while temperature is fairly high and that this activity declines in direct relationship to the falling temperature till the return of daylight puts an end to biting activity altogether.

TABLE VI.

Characteristics of Four-hour Climate Periods applicable both to Forest and to Banana Plantation.

Time (24-hour clock)	06–10	10–14	14–18	18–22	22–02	02–06
Temperature	Low	Highest	High	Low	Lower	Lowest
Relative humidity	Very high	Low	High	Very high	Very high	Very high
Saturation deficiency ..	Low	Highest	High	Low	Very low	Very low
Light	Low	High	Low	Very low	Lowest	Very low

In general, it is more difficult to arrive at conclusions concerning the activity of day-biting species, as all the climatic factors are changing simultaneously, though occasionally the persistence of high R.H. and low S.D. in the first morning period may give a clue. If a species bites actively by day, with a peak in the middle day period and continues to bite in small numbers throughout the night, it would be possible to argue that its activity is inversely proportional to R.H., or that it is directly proportional to temperature, S.D., or light. In such a case much laboratory work with controlled climate would be necessary to find which is the most important factor. Such work is not at present feasible. It is felt, however, that the results of the field experiments described below do indicate that the biting activity of mosquitos in their natural habitat is controlled, or at least profoundly influenced, by the microclimate. It is also suggested that the use of a four-hour grouping in the discussion of mosquito figures has been the most satisfactory simply because it agrees best with the main features of the daily climatic cycle.

Mosquito Catches.

Note on Systematics.

In the following sections certain mosquitos are referred to " groups " and not to species, for these reasons: The Bwamba mosquito fauna is a very varied one and includes many rare and little-known species. In the present scarcity of comparative material it is necessary to proceed with caution in identifying such forms. In other cases no really reliable characters are known for distinguishing the females of closely allied species, and it is obviously better to refer a specimen to the correct group than to the wrong species. Wherever possible, material is being sent to the Medical Research Laboratory at Nairobi and the Medical Laboratory at Kampala, and in other cases larvae are being reared to provide males for dissection. It will, however, be a long time before certain species can be identified with confidence.

The groups included in the present paper are as follow:

1. *Aëdes (Aëdimorphus) apicoannulatus* group.

This is a particularly confusing group of closely allied forms. Several are known to occur in Bwamba. The single female in the present series of catches closely resembled *A. (A.) haworthi,* Edw. Other species taken in routine catches have been provisionally assigned to *A. (A.) capensis,* Edw., *A. (A.) stokesi,* Ev., and *A. (A.) simulans,* N. & C. The group is considered here as defined by Edwards (1941).

2. *A. (A.) tarsalis-abnormalis* group.

Various members of this difficult group (which includes the *A. tarsalis* and *A. abnormalis* groups of Edwards' 1941 classification) have been definitely identified in Bwamba. Others are at the moment provisionally assigned to species, though not quite typical. At least one seems to be new. In view of the vague nature of the characters used in distinguishing females, collective treatment seems to be indicated here.

3. *Eretmapodites chrysogaster* group.

In Bwamba *E. chrysogaster,* Graham, *E. semisimplicipes,* Edw., and *E. grahami,* Edw., are all known to occur. It is doubtful whether the females can be distinguished reliably, and it seems better to treat these species collectively.

4. *E. dracaenae* group.

This " group " consists of a single species. It closely resembles *E. dracaenae,* Edw., both in the immature and adult stages, but examination of the male terminalia suggests that it is new. It will be discussed more fully in a subsequent communication. It is almost certain that Gibbins' records (1942) of *E. dracaenae* from Bwamba refer to this species.

5. *Culex* spp. indet.

In the absence of comparative material the writer does not feel competent to identify females of the more indeterminate species of *Culex.* The present group includes, among others, *C. (Culex) antennatus,* Beck., *C. (C.) univittatus,* Theo., members of the *C. (C.) decens,* Theo., group and a few *C. (Culiciomyia)* spp., probably *C. (C.) nebulosus,* Theo., and *C. (C.) macfiei,* Edw., both of which have been taken as larvae in Bwamba.

It is convenient to list here the species taken in the present series of catches, to allow the use of abbreviated names in subsequent discussion. The nomenclature and systematic arrangement are those of Edwards (1941).

Anopheles (Anopheles) paludis, Theo.
A. (A.) impexus, Theo. l
A. (Myzomyia) funestus, Giles
A. (M.) keniensis, Ev.
A. (M.) gambiae, Giles
A. (M.) pharoensis, Theo.
Uranotaenia balfouri, Theo.
Ficalbia (Mimomyia) plumosa, Theo.
Taeniorhynchus (Coquillettidia) pseudoconopas, Theo.
T. (C.) fuscopennatus, Theo.
T. (C.) aurites, Theo.
T. (Mansonioides) africanus, Theo.
T. (M.) uniformis, Theo.
Aëdes (Mucidus) grahami, Theo.
A. (Finlaya) longipalpis, Grünb.

A. (F.) ingrami, Edw.
A. (Stegomyia) aegypti, L.
A. (S.) simpsoni, Theo.
A. (S.) apicoargenteus, Theo.
A. (S.) africanus, Theo.
A. (Aëdimorphus) apicoannulatus, Edw., group
A. (A.) argenteopunctatus, Theo.
A. (A.) mutilus, Edw.
A. (A.) domesticus, Theo.
A. (A.) tarsalis, Newst.—*abnormalis,* Theo., group
A. (A.) cumminsi, Theo.
A. (A.) natronius, Edw.
A. (Banksinella) circumluteolus, Theo.
A. (B.) palpalis, Newst.
A. (Dunnius) sp.n.
Eretmapodites chrysogaster, Graham, group.
E. dracaenae, Edw., group
E. leucopus, Graham, subsp. *productus,* Edw.
Culex (Neoculex) horridus, Edw.
C. (Culex) poicilipes, Theo.
C. (C.) moucheti, Ev.

Certain of the above can be eliminated from further discussion. *U. balfouri* and *F. plumosa* have never been taken actually biting. They probably alighted on the baits casually. Though the larvae of *A. aegypti* are not uncommon in tree-holes in Bwamba, the adults are very rarely taken biting, and present evidence suggests that it may be largely sylvan and zoophilic in this area.

Methods used in making large-scale Routine Catches.

In the series of 24-hour catches described below, many of the common Bwamba species did not occur while others, poorly represented, have been taken quite abundantly in large-scale routine collections made in an attempt to isolate yellow fever virus from forest mosquitos. As figures obtained during this routine work will be included to help the discussion of species which were scarce in the 24-hour catches, it is appropriate to describe the methods normally employed in making these large collections.

During work in Kenya, the writer (1942) found that the number of mosquitoes taken in native huts was directly proportional to the number of human occupants. Applying this principle to open-air catching, large baits of native children (sometimes as many as 120) were used during the earlier catches, most of which were made in banana plantations. The children were divided into small parties, and the collecting was done by five to ten mosquito catchers under a supervisor. It was found that there was an optimum number of children per catcher as, if more than ten were included in each group, the catcher found difficulty in keeping all under adequate observation.

Later catches were made in more inaccessible areas, mainly in forest, and it was not possible to provide transport for large baits of native children. It was also found that both in forest and in banana plantations large stationary baits were not altogether satisfactory. During the first 15 minutes of a catch, mosquitos would be taken in large numbers, but after this the yield was usually poor. To overcome these difficulties the bait system was discarded altogether and the catches are now made by about 20 catchers, varying in age from 5 to 15 years, under a senior and two junior supervisors. Each catcher works individually and moves slowly from point to point. His salary is largely dependent on his efficiency. This method has proved satisfactory, the small group of experienced and mobile catchers being at least as effective as the large stationary bait. In forest, the great majority of mosquitos are taken on game paths and in the vicinity of wallows, water holes and streams. The catchers soon learn to select the best spots, and the present unit of 20 sometimes takes as many as 400 mosquitos in an hour. During the catch most of the catchers prefer to work almost naked but it is their common experience that the great majority of the mosquitos bite the legs, usually below the knee.

Mosquitos were at first caught in large suction tubes and were transferred to Barraud cages in the field. In the laboratory they were removed from the cages in small tubes, identified and recaged. It was found that mortality was always high in catches made by this method. This was partly due to the jostling of the mosquitos in the tubes and partly to the handling necessary in the laboratory. It has been found much better to use small tubes plugged with cotton, catching only one mosquito in each. Those at present in use are ordinary test tubes three and one-quarter by three-fourths inches in size. The catch is brought to the laboratory in covered baskets, and the mosquitoes are identified in the tubes and transferred at once to the cages. This method minimises handling, and mortality is never high. The cages are covered above by a pad of moist cotton, and banana (changed daily) is supplied as food. The wire frames of the cages are cubical with eight and three-quarter inch sides, the actual net cages having seven and one-half inch sides.

Figures from a recent catch may be quoted to show the effectiveness of these methods. Camp was pitched in forest at a considerable distance from the main road, and a catch was made over a period of five days; 5,337 female mosquitoes were taken and were identified and caged in camp. On the sixth day the cages, some of which contained over 300 mosquitoes, were carried out of the forest by porters, the journey to the road lasting about five hours. They were then taken to Bundibugyo by car. The following day they were sent by car to the Institute at Entebbe, a journey of 273 miles. On the day after that, 5,055 were found to be still alive. The total mortality over the eight-day period concerned was thus only 282 mosquitos, or just over 5 per cent. of the total catch.

Trial Catches made with Trap Nets.

In working out the details for a series of 24-hour catches, it seemed likely that the most serious fallacy would be that due to the use of lights for catching at night. It was thought that the employment of trap nets might overcome this difficulty, mosquitos being removed from the nets at clock hours only. Nets of various sizes were made, following the pattern described by Shannon (1939), and the following trials were made:

The first two tests were made overnight at the Yellow Fever Research Institute at Entebbe. On each night a monkey was confined in a cage inside a small trap net. On the first night a small baboon *(Papio doguera tesselatus,* Elliot) was used, and on the second, a red-tail monkey, *Cercopithecus nictitans mpangae,* Matschie (= *C.n. schmidti,* Matschie). In both cases *T. fuscopennatus,* which is abundant at Entebbe, entered the net freely. It was noted that most of the mosquitos soon escaped, particularly at sunrise, when almost all managed to find their way out. An attempt was made to make escape more difficult by slanting the outer side walls of the trap inward to decrease the size of the openings at the bottom of the trap chambers. The nets were then tried in forest in Bwamba.

In the first forest test, six fowls were placed in a cage inside a small trap net. The only species attracted during the four hours of the test was *A. cumminsi.* During the first two hours mosquitos were caught immediately on arrival in the trap.

During this period 24 mosquitos entered and all were caught. During the second two hours the mosquitos were counted as they entered the net but were caught at clock hours only. During this period 21 mosquitos entered the net. Only six were caught, and the remaining 15 escaped in the periods between the hourly catches.

A test was now made with human baits, including both day and night catches. Two native children of equal size were chosen. One sat inside the net and the other outside, at a distance of ten yards. Both were naked. In the case of the net, mosquitos were counted on arrival and identified with a hand lens, but were collected at clock hours only. In the case of the outside bait, mosquitos were caught in a suction tube immediately after they had alighted on the bait. One two-hour catch was made by day and one by night, using the same baits. In both cases the baits changed places after the first hour, to eliminate the effects of possible differences in attractiveness. During the night catch it was necessary to use a torch to catch mosquitos alighting on the outside bait and another to count and identify mosquitos entering the net. Exactly similar dimmed electric torches were used, and both were kept switched on throughout the experiment so that there should be no difference between the illumination of the baits. The torches were held by the baits themselves. The results were:

	Day Catch		*Night Catch*		*Combined*	
	Trap net	*Outside bait*	*Trap net*	*Outside bait*	*Trap net*	*Outside bait*
Entered net or alighted on bait	12	39	38	74	50	113
Caught	6	36	29	71	35	107
Escaped	6	3	9	3	15	6

These results showed that in the case of trap nets continuous catching was necessary unless many mosquitos were to be lost. In other words, the use of a trap net at night would have no advantage over hand catching, as the continuous use of a light would be necessary in either case. Further, the net was much less effective than hand catching. Thus, on the exposed bait, the number of mosquitos was almost exactly three times the number caught at clock hours in the net and more than twice the total number which entered the net. Of those which did enter, 30 per cent. escaped between the hourly catches, but in the case of the outside bait, only 5 per cent. escaped. Not only were more mosquitos attracted to the outside bait, but more species were also taken. Thus, while five species entered the net, eight species alighted on the exposed bait.

It has been implied above that in making comparative catches with human baits care must be taken to eliminate fallacies due to individual differences in attractiveness. The present catch demonstrates this point clearly. During both catches each child spent one hour inside the net and one hour outside. Taking the total number of mosquitos attracted to each during the whole test, it was found that bait "a" attracted 60 mosquitos belonging to four species, while bait "b" attracted 103 mosquitos belonging to nine species. Thus, though bait "b" was apparently similar to "a," he attracted almost twice as many mosquitos and more than twice as many species. It is obvious that, if misleading results are to be avoided, every effort must be made to avoid fallacies due to such differences in attractiveness, by such manoeuvres as changing over the baits at half time. It should be remembered that the differences may often be of a kind not perceptible by the human observer.

Methods used in making 24-hour Catches.

When a 24-hour catch was to be made, a tent was pitched near the selected spot and the catching squad slept in it overnight, beginning work at 06 hours the next morning. During the catch the baits (always naked children) sat in a circle on grass mats. The size of the bait varied from catch to catch, according to the number of children available, the smallest bait in any catch being five and the largest 16. In view of the difference in attractiveness between individuals, the baits were not changed during the course of a catch, except in the special circumstances detailed below. At first it was thought that the children would object to sitting naked in the open for 24 hours, but actually no trouble was experienced. They did not find the work tiring as they could sleep when they desired, as long as they did not move from their positions, and a five-minute free period was given at each clock hour. The baits, always volunteers from the junior mosquito catchers, received extra pay for the work, but actually their willingness to participate in catches was due to the issue of food in liberal quantities. They were allowed as much food as they could eat, and an extra boy acted as cook.

The actual collection was done by three catchers working in two-hour spells. In catching by night, a single hurricane lamp was used, the wick being well turned down and the light the dimmest which would allow work to proceed efficiently. In every catch, arrangements were made to allow a tarpaulin to be rigged quickly in the event of heavy rain. This only had to be used twice, for short periods. In both cases the tarpaulin was made fast about nine feet above the ground, to avoid interference with the catch. Two series of catches were made, 15 in the forest and 15 in banana plantations. The forest catches, amounting to 3,312 bait hours, were made in five different localities, varying from areas of second growth near the forest edge to others with an almost pure stand of African ironwood, deep in the main forest. The banana plantation catches were made in three different areas and totalled 4,824 bait hours.

A familiar feature of mosquito catching in the field is the considerable day-to-day fluctuation in the numbers of common species. Often periods of exceptional abundance may occur, and these may be of very short duration, perhaps only one to two hours. In an attempt to explain this phenomenon, the last four catches of each series were run continuously for four days and nights, in conjunction with climate observations. In these very prolonged catches the baits worked on a shift system, but only one child was changed each hour. The bait consisted of ten children, and as 15 were employed in all, each worked for ten-hour periods, separated by free periods of five hours each. A thermograph and hygrograph were set up in a screen actually at the catching area, detailed weather notes were kept, and light readings were made hourly. One or two very sudden fluctuations did occur in the case of certain species, but unfortunately it was not possible to correlate these with any special feature of the microclimate. It is thought that continuous catching for perhaps a month would be necessary for the proper investigation of these fluctuations. As it was, no information was added to that gained from ordinary 24-hour catching.

Special Catches of Aëdes simpsoni.

Work in Bwamba at first consisted mainly of collections of *A. simpsoni* in and around banana plantations, and several special catches were made at that time to investigate the biting habits of this important species.

At Bubukwanga, five miles north of Bundibugyo, the main road passes through extensive banana plantations. Catches were made here to discover whether *A. simpsoni* is to be found biting with equal activity throughout a plantation or whether it prefers certain parts. The areas selected were as follows:

1. The main road, which runs parallel to the edge of the selected plantation at a distance of about 20 yards. The intervening space is covered with grass one to two feet high.

2. A group of huts in the middle of the plantation. The huts were arranged in a circle in a clearing about 40 yards in diameter. Catching was carried on within the space enclosed by the huts.

3. A dense area with large banana plants up to about 18 feet high. In this part there was deep shade. Undergrowth was heavy and the bananas were festooned with creepers.

4. The edge of the plantation, 20 yards from the road catching station. The catch was made close beside the outermost plants, but not actually among them.

5. A rather open, recently planted area. Here the banana plants were all quite small (four to eight feet high) and the undergrowth had just been cleared.

On two successive mornings two-hour catches were made simultaneously by five catchers, one in each area. On the first day each worked with a bait of five children. On the second day the baits were increased to ten per group.

TABLE VII.

Results of Catches of Adult Mosquitos made in different Parts of a Banana Plantation.

Species	Road	Village clearing	Thick Part	Thin Part	Edge	Total
T. aurites	—	—	1	—	—	1
T. africanus	—	—	1	—	—	1
T. uniformis	—	—	—	2	—	2
A. simpsoni	3	7	11	75	165	261
A. cumminsi	—	—	5	—	—	5
A. circumluteolus	—	—	1	—	—	1
C. horridus	—	—	1	—	—	1
Total	3	7	20	77	165	272
Number of species ..	1	1	6	2	1	7

The results (Table VII) showed clearly that *A. simpsoni* was the dominant species. It made up 96 per cent. of the total catch. It occurred most abundantly in the thin part of the plantation, where 63 per cent. of its total numbers were taken, and it was also common round the edge, where 29 per cent. were caught. In the dense area it was not common, but here five additional species were taken which did not occur elsewhere On the road and in the village clearing it was scarce, showing that, while it will bite in the open actually outside a plantation, it does so in small numbers only and probably does not fly far. This is in agreement with Gibbins' results (1942). This finding applies only to actual open spaces for, where abundant vegetation surrounds a banana plantation, *A. simpsoni* may spread through it in considerable numbers. It penetrates the edges of forest for short distances and abounds in coffee gardens and elephant grass where these occur beside banana plantations. Maize fields form a favourite harbourage for adults; and a maize field beside a banana plantation is the most productive type of habitat in which to search for biting females.

In order to investigate the type of food preferred by *A. simpsoni*, catches were made on four types of bait; man, birds, goats and monkeys. Two two-hour catches were made, but as the results were almost identical, only the totals need be considered here. The baits, which were of approximately equal bulk, were placed side by side in a circle during the catches, which were made in native plantations. All the mosquitos taken were *A. simpsoni*. The results were:

Bait	*A. simpsoni*
Man (1 naked child)	58 (61%)
Birds (6 fowls)	23 (24%)
Goats (2 kids)	12 (13%)
Monkeys (2 young baboons)	2 (2%)
Total	95

This result seems to indicate a distinct preference for human blood. It was surprising to find that baboons attracted so few mosquitos and the fowls so many.

During Gibbins' work (1942), it was found that *A. simpsoni* seemed to prefer to bite the upper parts of the body. As numerous casual field observations in Bwamba tended to confirm this result, a catch was made in a maize field to investigate the apparent preference more critically. The bait consisted of six naked children arranged in pairs. To eliminate possible fallacies due to individual differences in attractiveness, the catch was carried out as follows: The total period of one hour was divided into six periods of ten minutes. During the first ten minutes two children stood, two sat, and two lay down. The pairs were then changed over and a further change was made at the end of the second ten minutes. Thus, after half an hour, each pair had occupied each posture for ten minutes. During the second half hour all six stood together for ten minutes, sat for ten minutes, and lay for ten minutes. It is thought that this procedure must have eliminated completely any bias due to differences in attractiveness among the baits.

Considering first the entire baits, it was found that *A. simpsoni* preferred standing to sitting and sitting to lying baits. The results are comparable, as all the children occupied all the postures for equal periods. The results are shown in the last column of the table below (" Total for the whole body ").

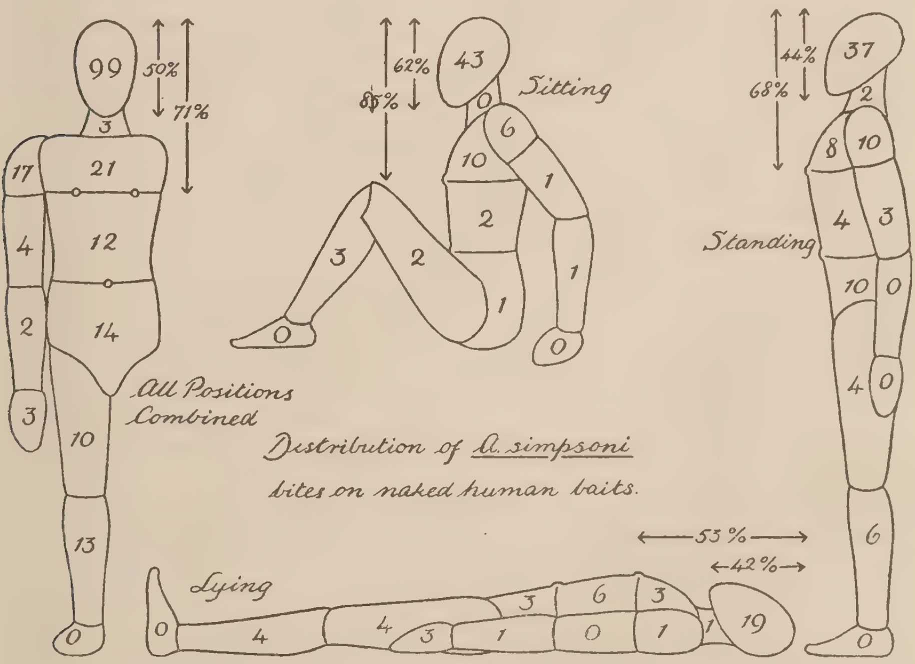
99
50%
71%
3
17
21
4
12
2
14
3
10
13
0
All Positions Combined
62%
85%
43
Sitting
0
6
10
1
2
3
2
1
1
0
0
44%
68%
37
2
8
10
4
3
Standing
10
0
4
0
6
0
Distribution of A. simpsoni bites on naked human baits.
53%
42%
Lying
0
4
4
3
1
3
6
0
3
1
1
19

Fig. 7. Distribution of *A. simpsoni* bites on naked human baits during a comparative experiment.

In noting the parts of the body bitten, the following areas were recognised: Head, neck, trunk above nipple line, trunk between nipple line and umbilical line, trunk below umbilical line, shoulders and arms above nipple line, arms below nipple line, forearms, hands, thighs, legs, feet. The results are best shown diagrammatically (fig. 7). It is enough to state here that *A. simpsoni* showed a marked preference for the head and after that the shoulders and upper trunk, no matter what the posture of the bait might be. The main results were as follows:

Posture	*Catch on head only*	*Catch above nipple line*	*Total for whole body*
Standing	37 (44%)	57 (68%)	84
Sitting	43 (62%)	59 (85%)	69
Lying	19 (42%)	24 (53%)	45
All postures	99 (50%)	140 (71%)	198

Thus, *A. simpsoni* bites mainly in maize fields, coffee gardens and the thinner parts and edges of banana plantations. It occurs within the edges of forest and also bites in the open to a small extent. It probably does not fly far. It appears to prefer human blood and attacks the head and upper trunk selectively, no matter what the posture of the host may be.

Comparison between the Mosquito Fauna of Banana Plantations and that of Rain Forest.

A clear demonstration of the difference between the mosquito fauna of a banana plantation and of primeval rain forest was given by the results of a simultaneous 24-hour catch in plantation and forest at Kanyamwerima, three miles north of Bundibugyo. Here the main road, running through level country, is bordered on the east by forest and on the west by large banana plantations, both forest and plantations actually reaching the roadside. As large routine catches had been made in this area, it was known to be a suitable one for experimental purposes. In the comparative catch each unit consisted of a bait of ten children. The plantation

Table VIII.

Results of a Simultaneous 24-hour Catch in Forest and a Banana Plantation.

Species or Group	Forest	Plantation	Total
A. paludis	1	—	1
A. implexus	1	1	2
A. keniensis	2	—	2
T. africanus	4	17	21
T. uniformis	2	1	3
A. longipalpis	3	1	4
A. ingrami	2	—	2
A. simpsoni	1	17	18
A. africanus	1	1	2
A. tarsalis-abnormalis group	5	—	5
A. cumminsi	12	21	33
A. circumluteolus	6	—	6
A. palpalis	4	2	6
E. chrysogaster group ..	1	1	2
E. dracaenae group	1	—	1
Culex spp. indet.	60	12	72
Total	106	74	180
Number of species and groups	16	10	16

unit was placed 20 yards west of the road among " gonja " bananas, with fairly heavy undergrowth. The forest unit was placed ten yards east of the road, from a point ten yards further north, in thick forest with abundant epiphytic growth. The distance in a straight line between the units was about 40 yards. The results are shown in Table VIII.

At first it was thought that the catches might be rather similar, as the units were so close to one another and to the edges of their respective environments. The results, however, showed clearly the difference between the mosquito populations of the two habitats. The main points to be noted are as follows: The number of species taken in forest (16) was much greater than that taken in the plantation (10), and no species was taken in the plantation which did not also occur in the forest. The actual number of mosquitos taken in the forest (106) was also much larger than the total of 74 from the plantation. In some ways the catch was not typical. Thus, *A. cumminsi* was unusually abundant in the plantation and *Culex* spp. were unusually abundant in the forest. It will be noted that in both cases the total catch

TABLE IX.

Results of Fifteen 24-hour Catches in Forest and 15 in Banana Plantations.

Species or group	Forest	Plantations	Total
A. paludis	43	3	46
A. implexus	5	2	7
A. funestus	9	1	10
A. keniensis	18	2	20
A. gambiae	405	7	412
A. pharoensis	—	4	4
U. balfouri	1	—	1
F. plumosa	2	—	2
T. pseudoconopas	5	—	5
T. fuscopennatus	270	21	291
T. aurites	2	2	4
T. africanus	126	156	282
T. uniformis	10	95	105
A. grahami	2	2	4
A. longipalpis	25	2	27
A. ingrami	4	—	4
A. aegypti	—	2	2
A. simpsoni	23	1,064	1,087
A. apicoargenteus	9	3	12
A. africanus	15	57	72
A. apicoannulatus group ..	1	—	1
A. argenteopunctatus	1	2	3
A. mutilus	2	—	2
A. domesticus	9	—	9
A. tarsalis-abnormalis group	93	1	94
A. cumminsi	542	71	613
A. natronius	2	—	2
A. circumluteolus	49	12	61
A. palpalis	186	3	189
A. (Dunnius) sp. n.	3	—	3
E. chrysogaster group ..	58	7	65
E. dracaenae group	25	3	28
E. leucopus ssp. *productus* ..	—	2	2
C. poicilipes	1	—	1
C. moucheti	13	—	13
Culex spp. indet.	226	328	554
Total	2,185	1,852	4,037
Number of species or groups	33	25	36

was quite small. This was invariably the case in 24-hour catches and was the result of the necessity for using small, closely grouped baits. The result shows how small are the numbers of *A. simpsoni* which penetrate even the extreme edge of the forest.

It is now necessary to consider the comparison between the mosquito fauna of plantations and forest as shown by the totals for the whole series of 24-hour catches (Table IX). Once again it is apparent that the variety of species in forest (33) is greater than that in plantations (25). The catching rate was also greater in forest than in plantations, 66 mosquitos per 100 bait hours as opposed to 38 per 100 bait hours. Only 3 species were taken in plantations which did not also occur in forest. One of these, *A. pharoensis,* occurs regularly in Bwamba in short " irruptions," probably originating from some distant breeding place. Its occurrence in either forest or plantations is to be regarded as purely casual. Another, *E. leucopus* subsp. *productus,* is never abundant, but the evidence of routine catches shows that it occurs mainly in forest and is scarce in banana plantations. As far as this species is concerned the figures in Table IX may be regarded as misleading.

The relative abundance of the different species in the two habitats cannot be gauged directly from Table IX, as the totals for the two series are not the same. The simplest method of estimating relative prevalence would be to express the plantation and forest totals for each species as percentages of the totals for the two series. As, however, the number of species is large, most of the percentages are very small. For example, in the forest series, a catch of 22 mosquitos would represent only 1 per cent. of the total. The procedure here followed has been to work out in detail the percentages for each species in both series and then to divide the larger figure by the smaller in each case. The result (Table X) is a simple ratio, giving the expected catch in the more favourable habitat for every one caught in the less favourable. Of course, this method can be applied only to species which occurred in both environments, and those which were very scarce (less than five taken) have been omitted.

TABLE X.

Results of Fifteen 24-hour Catches in Forest and 15 in Banana Plantations.

Species or group	Forest	Plantations
A. paludis	12	1
A. implexus	2	1
A. funestus	7	1
A. keniensis	8	1
A. gambiae	48	1
T. fuscopennatus	11	1
T. africanus	1	1
T. uniformis	1	11
A. longipalpis	11	1
A. simpsoni	1	55
A. apicoargenteus	3	1
A. africanus	1	5
A. tarsalis-abnormalis group	78	1
A. cumminsi	6	1
A. circumluteolus	3	1
A. palpalis	52	1
E. chrysogaster group ..	7	1
E. dracaenae group	7	1
Culex spp. indet.	1	2

Ratios showing the relative abundance of the more important species in forest and banana plantations.

All species of *Anopheles* were more abundant in forest than in plantations, even in the case of those not normally associated with a forest habitat. *A. gambiae* was the outstanding example, being 48 times as prevalent in forest as in plantation. *A. paludis* has been taken quite regularly in routine forest catches in many parts of Bwamba, but rarely occurs in plantations. *A. pharoensis* has been discussed above.

With regard to the genus *Taeniorhynchus*, the following points may be noted: *T. fuscopennatus* and *T. pseudoconopas* are rather abundant in Bwamba and have been found to occur mainly in forest. *T. aurites* has been taken regularly in routine catches in forest and plantations, but always in numbers too small to allow of an estimate of relative prevalence. The position with regard to *T. africanus* and *T. uniformis* is extremely interesting. These species normally occur together and their habits are strikingly similar. In Bwamba, however, the evidence of routine catches has shown that *T. africanus* is widely distributed in forest areas, while *T. uniformis* is scarce in forest except round extreme edges and in the vicinity of the watercourses where it breeds. In plantations it is often quite common. This finding is supported by the figures in Table X, which show that *T. africanus* was about equally prevalent in plantations and forest, while *T. uniformis* was eleven times as prevalent in plantations as in forest.

In the case of the genus *Aëdes*, the main points to be noted are as follows: *A. grahami, A. longipalpis, A. ingrami, A. apicoargenteus, A. domesticus*, and *A. (Dunnius)* sp.n., are all widely distributed, never very common, and largely confined to forest. *A. argenteopunctatus, A. mutilus* and the *A. tarsalis-abnormalis* group are locally abundant and occur almost entirely in forest. *A. cumminsi* is common in most areas and is also essentially a forest species in Bwamba, though it sometimes occurs in fair numbers in banana plantations. *A. natronius* occurs mainly around saline springs on the forest edge, though the specimens taken in the 24-hour catches were found two miles within the forest. The figures in Table X show that *A simpsoni* was 55 times as abundant in plantations as in forest, but it must be remembered that its occurrence within the forest edge, even in small numbers, is a point of considerable importance in assessing the yellow fever situation in Bwamba. In some parts of Africa it is known to be a tree-hole breeder (Dunn, 1926 & 1927), and in Bwamba, though it normally breeds in plant axils, larvae have sometimes been found in tree holes. The case of *A. africanus* is puzzling. This species is well known as a tree-hole breeder (Hopkins, 1936), and in Bwamba the larvae have so far been found in tree holes only. Yet the present catches showed that it was five times as abundant in plantations as in forest, and routine forest catches have never yielded large numbers. *A. circumluteolus* is placed by Edwards (1941) in the " Savannah group " of the subgenus *Banksinella* which are " specially associated with open savannah country." In the present series of catches, however, it occurred both in plantations and in forest, being three times as abundant in the forest as in plantations. This finding is supported by the routine catches, which have shown that it is widely distributed in the main forest, though never as numerous as the allied *A. palpalis*, a true forest species. In the Semliki Forest, *A. circumluteolus* is found mainly in the neighbourhood of watercourses and in frequently flooded areas where oil palms and acacias have largely replaced the original hardwoods.

An interesting problem is presented by the genus *Eretmapodites*. These mosquitos breed in leaf pools within the forest edge and to a small extent in tree holes. In plantations the larvae are extraordinarily abundant, inhabiting plant axils, leaf pools, and sometimes (in the case of *E. chrysogaster)* domestic receptacles. Adults, however, are always very scarce in plantations though often abundant in forest.

In the present paper little can be said about *Culex* spp. *C. poicilipes* is scarce in Bwamba, but seems to occur mainly in forest. *C. moucheti* is locally abundant, both in forest and in banana plantations.

It will be noted that the fauna of banana plantations in Bwamba includes many species usually associated with forest. As will be shown in the next section, this result has been obtained mainly by making night catches. Where a day catch in a plantation may consist almost entirely of *A. simpsoni,* night catches will often reveal many unsuspected but important species.

Comparison between the Results of Day and Night Catches.

Before discussing the results obtained by subdividing the 24-hour catch totals into day and night groups, it is convenient to consider the figures obtained in all day and night catches made in Bwamba up to the time of writing (Table XI). Numerous species not found in the 24-hour catches have been taken in the course of routine

TABLE XI.

Totals of All Day and Night Catches in Bwamba to Date.

Species or group	Day	Night	Total
A. paludis	20	40	60
A. implexus	20	6	26
A. funestus	3	286	289
A. keniensis	1	19	20
A. gambiae	116	3,214	3,330
A. pharoensis	—	24	24
U. balfouri	—	1	1
F. plumosa	1	2	3
T. pseudoconopas	869	5	874
T. fuscopennatus	140	272	412
T. aurites	154	8	162
T. africanus	305	1,172	1,477
T. uniformis	78	1,286	1,364
A. grahami	—	4	4
A. longipalpis	58	—	58
A. ingrami	45	2	47
A. aegypti	5	—	5
A. simpsoni	8,449	27	8,476
A. apicoargenteus	182	2	184
A. africanus	48	61	109
A. apicoannulatus group ..	49	—	49
A. argenteopunctatus	559	2	561
A. mutilus	537	1	538
A. domesticus	291	3	294
A. tarsalis-abnormalis group	8,454	54	8,508
A. cumminsi	4,107	533	4,640
A. natronius	17	1	18
A. circumluteolus	1,224	32	1,256
A. palpalis	10,161	39	10,200
A. (*Dunnius*) sp. n.	60	—	60
E. chrysogaster group ..	1,425	18	1,443
E. dracaenae group	1,160	3	1,163
E. leucopus subsp. *productus*	68	—	68
C. poicilipes	41	1	42
C. moucheti	4,021	1	4,022
Culex spp. indet.	9,956	794	10,750
Other species	2,739	34	2,773
Total	55,363	7,947	63,310

Only those species which occurred in the series of 24-hour catches are listed. The remainder are grouped under " other species."

work, and in Table XI these are listed collectively as "other species." The figures show that very few mosquitos bite exclusively by day or by night, though almost all show a preference for one or the other. In Table XI, *A. pharoensis* and *A. grahami* are recorded as night biters only, but *A. grahami* has once been taken biting in forest by day. This mosquito is not listed in the table as it occurred casually, and not in the course of a recorded catch. With regard to species listed as biting by day only, the following points may be noted: The figures for the *A. apicoannulatus* group probably present a true picture of the habits, as the results for the other small *Aëdimorphus* spp. all show evidence of a marked preference for biting by day. This also applies to *A. longipalpis*. Nothing is known of the habits of the new *Aëdes (Dunnius)* sp., except that it is widely distributed in forest, bites man, and is usually taken in catches made in the morning.

TABLE XII.

Results of All Day and Night Catches in Bwamba to Date. Relative Prevalence of the main Species by Day and by Night.

Species or group	Day	Night
A. paludis	1	14
A. implexus	1	2
A. funestus	1	720
A. keniensis	1	120
A. gambiae	1	193
T. pseudoconopas	25	1
T. fuscopennatus	1	14
T. aurites	3	1
T. africanus	1	27
T. uniformis	1	115
A. ingrami	3	1
A. simpsoni	45	1
A. apicoargenteus	13	1
A. africanus	1	9
A. argenteopunctatus	40	1
A. mutilus	75	1
A. domesticus	14	1
A. tarsalis-abnormalis group ..	23	1
A. cumminsi	1	1
A. natronius	2	1
A. circumluteolus	6	1
A. palpalis	37	1
E. chrysogaster group	11	1
E. dracaenae	55	1
C. poicilipes	6	1
C. moucheti	559	1
Culex spp. indet.	2	1

Only those species which occurred in the series of 24-hour catches are listed.

In order to allow comparison between the day and night figures for the remaining species, ratios have been worked out by the method described above (Table XII). Scarce species (five or less taken) are not included. The table shows that all species of *Anopheles* are mainly nocturnal, in most cases to a marked degree. It should be noted, however, that in the case of *A. implexus* a large proportion was taken by day. This is the only species of *Anopheles* in the present records which appears to be confined to forest and other dense, moist vegetation. This point will be discussed below. In the genus *Taeniorhynchus* two distinct groups occur, *T. pseudoconopas* and *T. aurites* biting mainly by day, while *T. fuscopennatus*, *T. africanus* and *T. uniformis* are largely nocturnal. Most species of *Aëdes* bite principally by day, with the exception of *A. africanus* and *A. cumminsi*. The most distinctly diurnal species are *A. simpsoni*, the small *Aëdimorphus* spp. and *A. palpalis*. All species of *Eretmapodites* so far taken in Bwamba (including scarce species not discussed here) are very largely day biters. In the case of the genus *Culex* little can be said at the moment. *C. moucheti* is definitely diurnal and sometimes occurs in very large numbers in catches made in the morning. The remaining group of unidentified *Culex* spp. is probably too heterogeneous to allow conclusions to be drawn, but there is reason to believe that many of the small species are mainly nocturnal.

In considering the results of the 24-hour catches (Table XIII), an important point concerns the relative numbers of species taken by day and by night in forest

Table XIII.

Entire Series of 24-hour Catches. Day and Night Totals.

Species or group	Forest			Plantations			Combined		
	Day	Night	Total	Day	Night	Total	Day	Night	Total
A. paludis	10	33	43	—	3	3	10	36	46
A. implexus	3	2	5	—	2	2	3	4	7
A. funestus	3	6	9	—	1	1	3	7	10
A. keniensis	1	17	18	—	2	2	1	19	20
A. gambiae	54	351	405	—	7	7	54	358	412
A. pharoensis	—	—	—	—	4	4	—	4	4
U. balfouri	—	1	1	—	—	—	—	1	1
F. plumosa	—	2	2	—	—	—	—	2	2
T. pseudoconopas	—	5	5	—	—	—	—	5	5
T. fuscopennatus	20	250	270	—	21	21	20	271	291
T. aurites	1	1	2	—	2	2	1	3	4
T. africanus	26	100	126	1	155	156	27	255	282
T. uniformis	4	6	10	4	91	95	8	97	105
A. grahami	—	2	2	—	2	2	—	4	4
A. longipalpis	25	—	25	2	—	2	27	—	27
A. ingrami	2	2	4	—	—	—	2	2	4
A. aegypti	—	—	—	2	—	2	2	—	2
A. simpsoni	21	2	23	1,039	25	1,064	1,060	27	1,087
A. apicoargenteus	8	1	9	2	1	3	10	2	12
A. africanus	6	9	15	7	50	57	13	59	72
A. apicoannulatus group	1	—	1	—	—	—	1	—	1
A. argenteopunctatus	1	—	1	—	2	2	1	2	3
A. mutilus	1	1	2	—	—	—	1	1	2
A. domesticus	6	3	9	—	—	—	6	3	9
A. tarsalis-abnormalis group	46	47	93	—	1	1	46	48	94
A. cumminsi	223	319	542	7	64	71	230	383	613
A. natronius	1	1	2	—	—	—	1	1	2
A. circumluteolus	33	16	49	1	11	12	34	27	61
A. palpalis	148	38	186	2	1	3	150	39	189
A. (*Dunnius*) sp. n.	3	—	3	—	—	—	3	—	3
E. chrysogaster group	45	13	58	4	3	7	49	16	65
E. dracaenae group	24	1	25	1	2	3	25	3	28
E. leucopus ssp. *productus*	—	—	—	2	—	2	2	—	2
C. poicilipes	—	1	1	—	—	—	—	1	1
C. moucheti	12	1	13	—	—	—	12	1	13
Culex spp. indet.	49	177	226	14	314	328	63	491	554
Total	777	1,408	2,185	1,088	764	1,852	1,865	2,172	4,037
Number of species and groups	28	29	33	14	22	25	30	31	36

and in plantations. In forest the number by day (28) was almost the same as that by night (29), but in plantations, while only 14 species were taken by day, 22 were found by night, an increase of more than 30 per cent. It is believed that this increase is largely due to the diffusion of forest mosquitos into banana plantations by night.

If a species bites mainly in forest and banana plantations, it may be assumed that it prefers a cool, moist habitat, and the climate records have shown that such conditions prevail in forest at all hours. By night such a species should find a favourable environment in banana plantations, as the climate of forest and plantations are very similar at this time. By day, however, the plantation, now warmer and much drier than the forest, will probably be less favourable or perhaps quite unsuitable. Table XIII shows that in the present series 22 species were common to forest and plantations. Their day and night distribution is summarised in Table XIV, which lends support to the argument for, while 20 of the 22 occurred in both environments by night, only 12 were common to both by day. Further, of these 12, several, such as *A. longipalpis*, are almost exclusively diurnal. Thus, the number of species common to both habitats by night is about twice the number common to both by day.

TABLE XIV.

List of the 22 Species or Groups which occurred both in Forest and in Plantations, to show their Distribution by Day and by Night. Results of 24-hour Catches.

Species or group	Day		Night	
	Forest	Plantations	Forest	Plantations
A. paludis	+	—	+	+
A. implexus	+	—	+	+
A. funestus	+	—	+	+
A. keniensis	+	—	+	+
A. gambiae	+	—	+	+
T. fuscopennatus	+	—	+	+
T. aurites	+	—	+	+
T. africanus..	+	+	+	+
T. uniformis	+	+	+	+
A. grahami	—	—	+	+
A. longipalpis	+	+	—	—
A. simpsoni	+	+	+	+
A. apicoargenteus	+	+	+	+
A. africanus	+	+	+	+
A. argenteopunctatus	+	—	—	+
A. tarsalis-abnormalis group	+	—	+	+
A. cumminsi	+	+	+	+
A. circumluteolus	+	+	+	+
A. palpalis	+	+	+	+
E. chrysogaster group	+	+	+	+
E. dracaenae group	+	+	+	+
Culex spp. indet.	+	+	+	+

While certain forest species occur in banana plantations by night only, others are found there by day also. Now, if the plantations should prove rather unfavourable by day, there should be evidence that the activity of forest species is somewhat restricted in them at this time. Thus, in the case of such species, it would be expected that the percentage taken by day of the total plantation catch would be lower than the percentage taken by day of the total forest catch. In Table XV are listed the species known to frequent both environments and to bite both by night and by day (omitting very scarce species). The table shows that in

TABLE XV.

Percentage taken by Day in Forest and in Plantations of the main Species known to bite by Day and by Night. Results of 24-hour Catches.

Species, group or genus	Percentage taken by day in forest	Percentage taken by day in plantations
A. paludis	23	—
A. funestus	33	—
A. keniensis	6	—
A. gambiae	13	—
T. fuscopennatus	7	—
T. africanus	21	Under 1
T. uniformis	40	4
A. simpsoni	91	98
A. apicoargenteus	89	67
A. africanus	40	12
A tarsalis-abnormalis group	49	—
A. cumminsi	41	1
A. circumluteolus	67	8
A. palpalis	80	67
E. chrysogaster group	78	57
E. dracaenae group	96	33
Culex spp. indet.	22	4
Anopheles, all species	15	—
Taeniorhynchus, all species	12	2
Aëdes, all species except *A. simpsoni*	53	15
Aëdes, all species including *A. simpsoni*	54	87
Eretmapodites, all species	83	58
Culex, all species	25	4

every case, except that of the specialised *A. simpsoni,* the percentage of the plantation catch taken by day was lower than the percentage of the forest catch taken by day. The second section of the table shows that the principle may even be applied to entire genera, though in the case of *Aëdes* the figures for *A. simpsoni* influence the result to such an extent that it has been necessary to show the results both including and excluding this species. The phenomenon is so clear-cut that in the case of the figures for entire genera it has been possible to include all species taken in 24-hour catches and not merely those included in the first part of the table.

So far it has been suggested that many forest species frequent banana plantations, that they find a favourable environment there by night, but a less favourable or entirely unsuitable one by day. It has also been suggested that these species do not properly belong to the fauna of plantations, but that they diffuse into them by night from the forest. Very strong evidence pointing to such migration is found in the presence of such tree-hole breeders as *A. longipalpis, A. apicoargenteus* and *A. africanus* in banana plantations. In Bwamba none of these species has so far been found breeding outside the forest, and their larvae, very abundant in tree holes, have not as yet been found in any other type of breeding place. Adults, on the other hand, are to be found biting in banana plantations, sometimes at some distance from the forest. The rigid restriction of many forest species to their habitat by day is probably due to the unfavourable climate of the open air. Even in banana plantations they occur mainly in the densest parts (Table VII). By night, however, the climate of the open air approximates to that of forest and with the breakdown of the climatic barrier there seems to be no serious obstacle to migration into the surrounding country.

The application of these findings to yellow fever epidemiology is obvious. In Bwamba the only vector so far definitely incriminated is *A. simpsoni*, which occurs mainly in and around native plantations in the vicinity of huts. It has now been shown that it enters at least the edge of the rain forest and bites there. It could thus obtain the virus by biting an infected animal in the forest and might thereafter pass on the disease to man. It seems still more likely that natives might be infected in their plantations by the bites of other species coming from the forest. It may be objected that most Africans retire early to their huts and are not likely to be bitten in plantations by night, but it should be remembered that small numbers of forest mosquitos bite in plantations by day, and it will be shown in the next section that several forest species bite mainly during the dawn and sunset periods, when natives are active among their crops.

Infection from the forest might even be conveyed to natives in the huts themselves, for the writer has shown (1942) that some " wild " species enter huts by night, bite, and leave again before sunrise, their activities remaining unsuspected unless night catches are made. *T. africanus* may be discussed as a good example, though further experience may well show other species to have the same characteristics. Table XIII shows that this mosquito bites in forest by day in small numbers, at which time it is very scarce in plantations. Just after sunset its activity in forest increases greatly and it may also be found biting quite freely in plantations. When it is added that this species is an effective laboratory transmitter of yellow fever (Philip, 1930), that it is widely distributed in forest in Bwamba, that it travels widely and that it bites both in the open and in huts and tents (in the latter cases leaving before sunrise), it will be realised that it could act as a very efficient vector in conveying the infection from animals to man.

Thus, while man-to-man transmission of yellow fever in Bwamba is almost certainly to be attributed to *A. simpsoni*, it seems likely that animal-to-man transmission may be the work of another species, probably a forest mosquito. It should be remembered that in Bwamba the highest incidence of human immunity occurs in areas where cultivation adjoins the main forest (Mahaffy & others, 1942), and a rational explanation may be found in the constant interchange which appears to go on between the mosquitos which inhabit the forest and those of neighbouring banana plantations.

Analysis of the 24-hour Catches by Four-hour Periods.

As has been mentioned above, a four-hour grouping was found to be the best for the analysis of mosquito figures, but in considering the results it is important that the idea of clock hours should be discarded except as a guide to the successive climatic phases of the day and night. In analysing biting cycles it has been convenient, in most cases, to use the combined figures for forest and plantations, to increase the size of the sample (Table XVI). The results for the main species are shown in fig. 8. The first intention was to prepare these histograms by means of percentages, each column showing the percentage of the total catch taken in that particular period. It was found, however, that this method led to great exaggeration of the columns in the case of species, such as *A. africanus*, which have a restricted period of activity. Accordingly, each has been drawn to a different scale, the highest columns all being of the same height. The six columns of each represent the six four-hour periods, beginning with Period 1 (06 to 10 hours). Thus in each case the first three columns represent day catches and the last three, night catches. In this section two papers will be referred to frequently. The first, by Kerr (1933), deals with open air night catches in West Africa, while the second, by the writer (1942), is mainly concerned with night catches in huts and tents at Kisumu, Kenya. For the sake of brevity, these will be referred to merely as " Kerr " and " Kisumu." The main species may now be discussed:

Table XVI.

Entire Series of 24-hour Catches in Forest and Banana Plantations. Four-hour Grouping.

Locality	Forest							Plantations							Combined						
Period	1	2	3	4	5	6		1	2	3	4	5	6		1	2	3	4	5	6	
Hours L.M.T. ..	06–10	10–14	14–18	18–22	22–02	02–06	Total	06–10	10–14	14–18	18–22	22–02	02–06	Total	06–10	10–14	14–18	18–22	22–02	02–06	Total
A. paludis	2	4	4	12	10	11	*43*	—	—	—	1	2	—	*3*	2	4	4	13	12	11	*46*
A. implexus	—	3	—	1	—	1	*5*	—	—	—	2	—	—	*2*	—	3	—	3	—	1	*7*
A. funestus	—	1	2	—	1	5	*9*	—	—	—	1	—	—	*1*	—	1	2	1	1	5	*10*
A. keniensis	—	—	1	7	5	5	*18*	—	—	—	1	1	—	*2*	—	—	1	8	6	5	*20*
A. gambiae	47	4	3	66	141	144	*405*	—	—	—	3	2	2	*7*	47	4	3	69	143	146	*412*
A. pharoensis ..	—	—	—	—	—	—	—	—	—	—	3	1	—	*4*	—	—	—	3	1	—	*4*
U. balfouri	—	—	—	1	—	—	*1*	—	—	—	—	—	—	—	—	—	—	1	—	—	*1*
F. plumosa	—	—	—	—	—	2	*2*	—	—	—	—	—	—	—	—	—	—	—	—	2	*2*
T. pseudoconopas ..	—	—	—	1	3	1	*5*	—	—	—	—	—	—	—	—	—	—	1	3	1	*5*
T. fuscopennatus ..	7	3	10	78	80	92	*270*	—	—	—	10	4	7	*21*	7	3	10	88	84	99	*291*
T. aurites	1	—	—	—	1	—	*2*	—	—	—	1	—	1	*2*	1	—	—	1	1	1	*4*
T. africanus	12	8	6	50	19	31	*126*	1	—	—	60	53	42	*156*	13	8	6	110	72	73	*282*
T. uniformis	3	—	1	6	—	—	*10*	3	—	1	50	18	23	*95*	6	—	2	56	18	23	*105*
A. grahami	—	—	—	1	1	—	*2*	—	—	—	1	1	—	*2*	—	—	—	2	2	—	*4*
A. longipalpis ..	2	16	7	—	—	—	*25*	—	2	—	—	—	—	*2*	2	18	7	—	—	—	*27*
A. ingrami	—	—	2	2	—	—	*4*	—	—	—	—	—	—	—	—	—	2	2	—	—	*4*
A. aegypti	—	—	—	—	—	—	—	—	—	2	—	—	—	*2*	—	—	2	—	—	—	*2*
A. simpsoni	2	9	10	1	—	1	*23*	341	326	372	12	5	8	*1064*	343	335	382	13	5	9	*1087*
A. apicoargenteus ..	1	2	5	—	1	—	*9*	—	—	2	—	—	1	*3*	1	2	7	—	1	1	*12*
A. africanus	—	1	5	6	2	1	*15*	5	2	—	45	4	1	*57*	5	3	5	51	6	2	*72*
A. apicoannulatus group	—	—	1	—	—	—	*1*	—	—	—	—	—	—	—	—	—	1	—	—	—	*1*
A. argenteopunctatus ..	—	—	1	—	—	—	*1*	—	—	—	1	1	—	*2*	—	—	1	1	1	—	*3*
A. mutilus	—	1	—	—	—	1	*2*	—	—	—	—	—	—	—	—	1	—	—	—	1	*2*
A. domesticus	3	1	2	—	2	1	*9*	—	—	—	—	—	—	—	3	1	2	—	2	1	*9*
A. tarsalis-abnormalis group	18	14	14	25	10	12	*93*	—	—	—	1	—	—	*1*	18	14	14	26	10	12	*94*
A. cumminsi	84	56	83	143	74	102	*542*	6	—	1	28	23	13	*71*	90	56	84	171	97	115	*613*
A. natronius	—	1	—	1	—	—	*2*	—	—	—	—	—	—	—	—	1	—	1	—	—	*2*
A. circumluteolus ..	11	12	10	5	8	3	*49*	—	—	1	5	4	2	*12*	11	12	11	10	12	5	*61*
A. palpalis	48	44	56	13	14	11	*186*	2	—	—	—	1	—	*3*	50	44	56	13	15	11	*189*
A. (*Dunnius*) sp. n. ..	1	—	2	—	—	—	*3*	—	—	—	—	—	—	—	1	—	2	—	—	—	*3*
E. chrysogaster group	7	20	18	4	4	5	*58*	—	1	3	1	1	1	*7*	7	21	21	5	5	6	*65*
E, dracaenae group ..	3	12	9	1	—	—	*25*	—	—	1	2	—	—	*3*	3	12	10	3	—	—	*28*
E, leucopus subsp. *productus*	—	—	—	—	—	—	—	1	—	1	—	—	—	*2*	1	—	1	—	—	—	*2*
C. poicilipes	—	—	—	—	1	—	*1*	—	—	—	—	—	—	—	—	—	—	—	1	—	*1*
C. moucheti	5	3	4	—	—	1	*13*	—	—	—	—	—	—	—	5	3	4	—	—	1	*13*
Culex spp. indet. ..	17	11	21	83	69	25	*226*	10	1	3	165	97	52	*328*	27	12	24	248	166	77	*554*
Total	*274*	*226*	*277*	*507*	*446*	*455*	*2185*	*369*	*332*	*387*	*393*	*218*	*153*	*1852*	*643*	*558*	*664*	*900*	*664*	*608*	*4037*

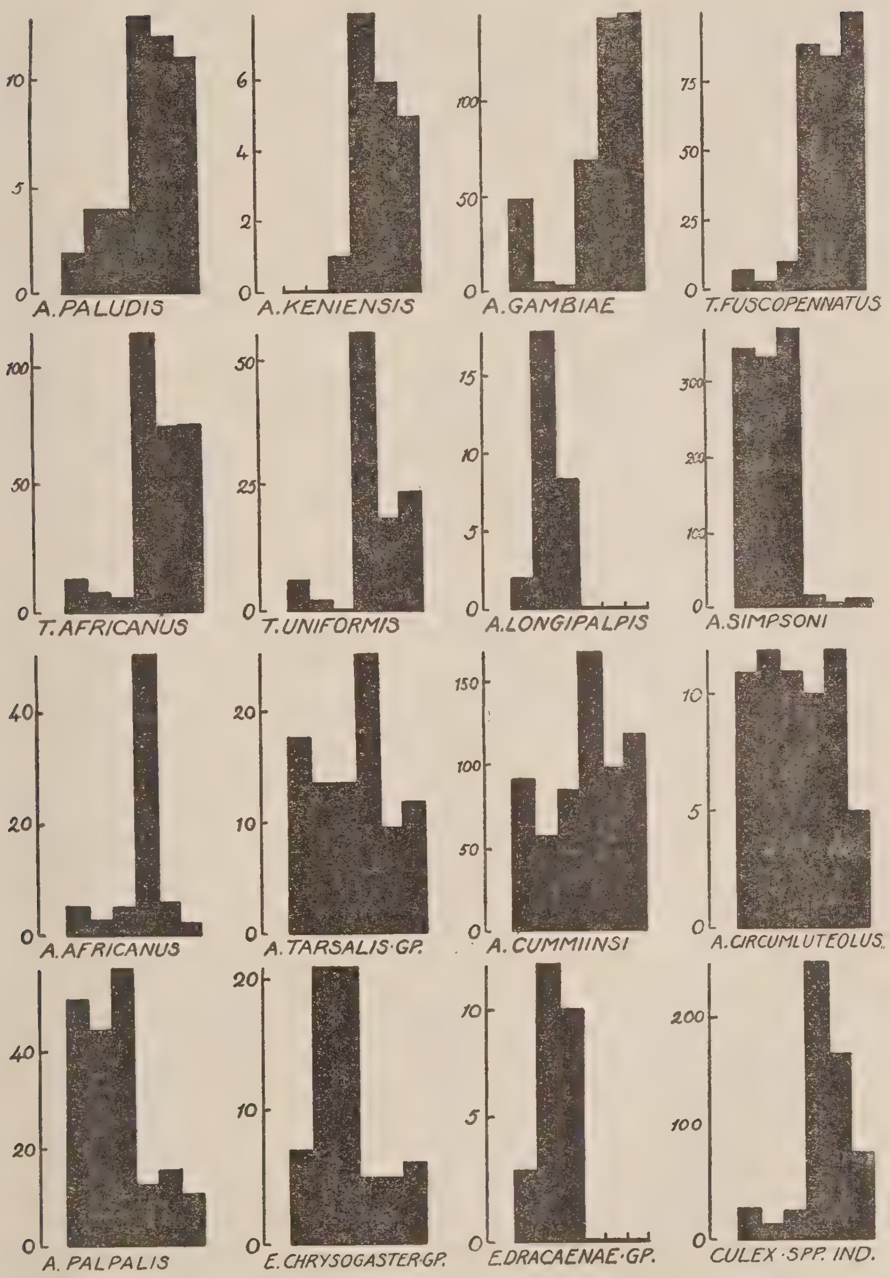

Fig. 8.—The biting cycle of the more important species taken in 24-hour catches. The six columns of each histogram represent the six four-hour periods used, namely: 06–10, 10–14, 14–18, 18–22, 22–02 and 02–06 hours. Thus the first three columns show day figures and the second, three night figures.

Anopheles paludis.

This species is largely nocturnal, and it seems likely that biting activity remains at a fairly even level throughout the night, the differences here recorded being quite trivial. Kisumu figures for the closely allied *A. coustani* var. *ziemanni*, Grünb., show a different type of curve, with a clearly marked peak in the middle night period. The only conclusion which can be reached at present is that *A. paludis* bites mainly in darkness, under conditions of low temperature and very low S.D.

Anopheles keniensis.

This species probably behaves similarly to *A. paludis*. The decrease shown during the successive night periods is probably not significant, but a much larger sample would be necessary before a decision could be made on this point.

Anopheles gambiae.

The biting activity of this species is clearly connected with one or more factors of the microclimate, as is shown in fig. 9. In this figure the numbers per period are shown as percentages to allow direct comparison with *Eretmapodites* spp. During Period 1 (06 to 10 hours) the catch was quite large, and it therefore seems likely that light is not the most important factor, as most of this period is full daylight. R.H. is a very artificial factor, mainly useful in the calculation of S.D., and will be disregarded in this and subsequent discussions. It is therefore suggested that the biting activity of this species is probably mainly influenced by temperature, S.D., or both. The relationship is an inverse one, the numbers of *A. gambiae* decreasing as temperature and S.D. rise and vice versa. Beyond this suggestion it is not possible to go without climate work in the laboratory. Kerr's figures show results rather similar to the present series, the main period of activity being after midnight. The Kisumu catches are also in agreement, except that they show a very marked increase at dawn. This peak was due to mosquitos entering the huts concerned for daytime shelter and had probably no relation to the biting cycle.

Taeniorhynchus fuscopennatus.

This species is essentially nocturnal. In the histogram, small peaks are apparent in the first and last night periods, and it is believed that these are real, though inconstant, as in individual catches they have sometimes been very clearly marked. It may be that activity in these periods is stimulated by suitable conditions of low light intensity. The light after sunset and before sunrise is very variable, and this variability could account for the inconstancy of the peaks. Now, while this species is abundant throughout the night, its incidence decreases sharply after sunrise. This also suggests that light may be an important factor, as it has been shown that during the sunrise and morning period (06 to 10 hours) the other main factors (temperature and S.D.) do not change greatly from their night levels, while light increases rapidly. The general conclusion is that this species bites by night, when temperature and S.D. are low and that its normal activity in the sunset and dawn periods may perhaps be augmented when light conditions are suitable.

Taeniorhynchus africanus and *T. uniformis.*

The biting curves of these species are similar and may be discussed together. Both are mainly nocturnal and show a well marked peak of activity after sunset. Activity during the rest of the night is high, but far below the sunset level. Both Kerr's figures and the Kisumu results show similar curves. It is thought that temperature is important and that these species bite mainly in darkness, under conditions of very low S.D., reaching their peak activity while temperature is still fairly high, at least in comparison with the later night periods.

Aëdes longipalpis.

This day biting species shows a very marked period of activity in the middle day period (10 to 14 hours), when temperature, S.D., and light are at their maximum. This is regarded as being characteristic of species dwelling in forest and other dense vegetation, as only in such surroundings are favourable climate conditions to be found at this time.

Aëdes simpsoni.

This species is almost exclusively diurnal. Fig. 8 shows small peaks in the morning (Period 1) and late afternoon (Period 3). These peaks were very pronounced in some catches, mainly in hot, dry weather, while in cloudy weather a very even level was usually maintained throughout the day. It seems likely that the activity of this species is restricted, though not brought to a standstill, by high temperature, S.D., or light. This argument is supported by the fact that it rarely bites in exposed situations, and then only in the immediate vicinity of banana plantations or other dense herbage. Similar results were obtained in Bwamba by Gibbins (1942), who found that *A. simpsoni* was most active on humid days, and that it bit most actively in the forenoon and late afternoon.

Aëdes africanus.

While most *Stegomyia* spp. are essentially diurnal, this species is definitely crepuscular, with a very distinct biting peak after sunset. At this time S.D. and light are low, but this also applies to the period before sunrise, when no marked activity occurs. As in the case of *T. africanus* it seems likely that the difference between the behaviour in these two periods may be due to the fact that while the air is quite warm after sunset, it is cool, often cold, before dawn.

Aëdes tarsalis-abnormalis group.

Members of this group bite mainly by day. The peaks shown in Period 4 (18 to 22 hours) and Period 6 (02 to 06 hours) are due almost entirely to very short phases of heightened activity about the times of sunset and sunrise.

Aëdes cumminsi.

This species may be taken biting at any time of the day or night, but its highest activity occurs just after sunset. This active period often lasts for only about one hour. Once again the combination of low S.D. and light intensity with moderate temperature seems to be important.

Aëdes circumluteolus and *A. palpalis.*

Both of these species are mainly diurnal, reaching their greatest activity in the morning and late afternoon, as in the case of *A. simpsoni.* It is thought that the numbers of *A. circumluteolus* taken by night in the present series are much above the normal, and the present statement is based on the evidence of routine catches.

Eretmapodites chrysogaster and *E. dracaenae* groups.

These groups show marked activity in the middle day and afternoon periods. As in the case of *A. longipalpis,* this is attributed to the fact that they are almost restricted to forest and other dense vegetation where midday climate extremes are slight. The close relationship between their biting cycle and the forest microclimate is shown in fig. 9. At present it is not possible to decide which is the controlling factor. Kerr was led by the evidence of night catches to assume that *E. chrysogaster* does not bite man in nature, but present evidence shows that he was studying the mosquito at a time when it is very inactive.

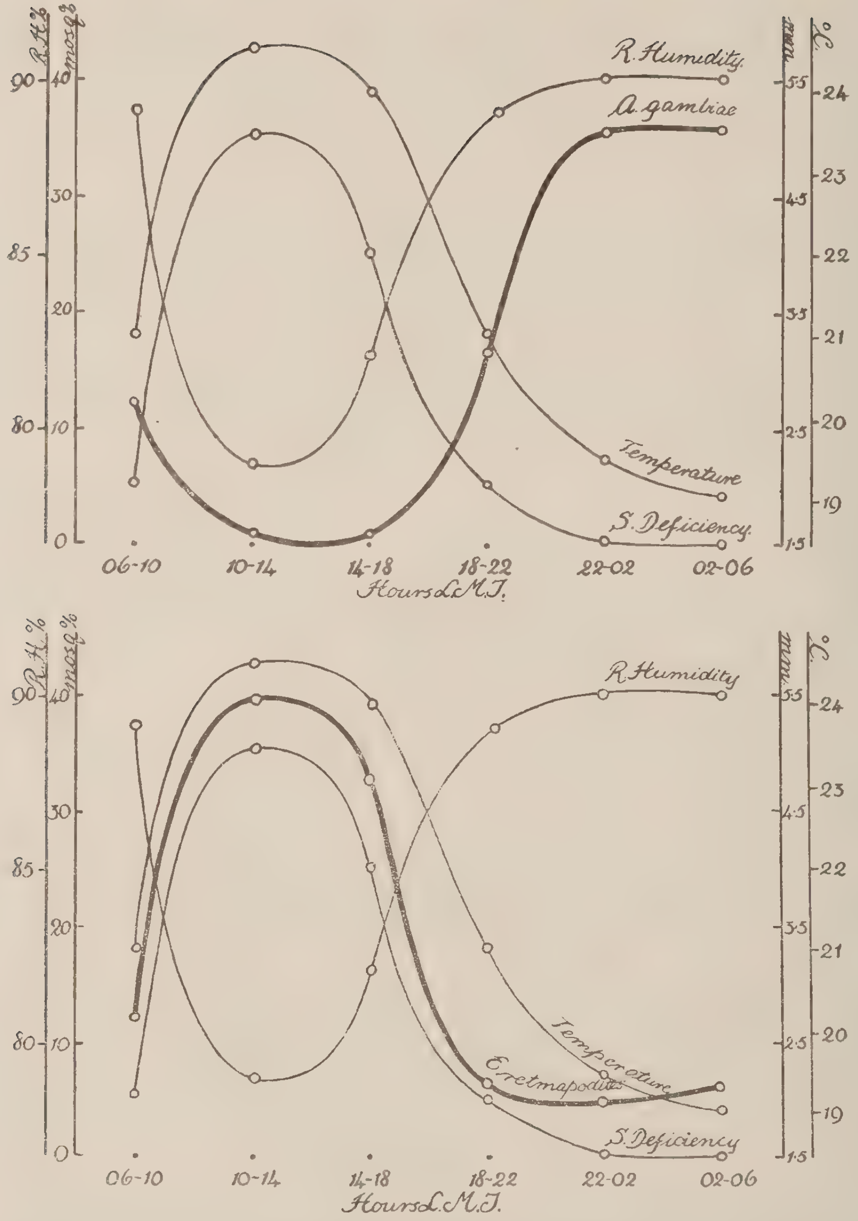

Fig. 9.—Results of 24-hour catches and climate observations in forest, to show the biting cycles of *A. gambiae* and *Eretmapodites* spp. in relation to the microclimate. To allow direct comparison, the numbers of *A. gambiae* and *Eretmapodites* spp. in each period are shown as percentages of their respective totals.

Culex spp. indet.

Though this group is a very heterogeneous one, it is clear that many species are mainly nocturnal, with a peak after sunset.

Discussion.

The number of types of biting cycle shown by species taken in the present series was very limited. None showed more than two peaks of activity in the 24 hours. The main findings may be summarised as follows:

A. *One peak of activity in 24 hours*

When this occurs by day the mosquito is usually a forest species such as *A. longipalpis*, which is not exposed to marked extremes of climate at any time. When the peak is crepuscular, as in the case of *A. africanus*, it is probably due to a combination of factors. Thus, if a species prefers to bite under conditions of low S.D. and light intensity, and if its activity is restricted by extremes of temperature, then the sunset period is the only time when it will find suitable climate conditions.

B. *Two peaks of activity in 24 hours*

In the case of diurnal species such as *A. simpsoni*, periods of heightened activity usually occur in the morning and late afternoon, the latter peak being the more pronounced. The midday decrease is probably due to the climatic extremes of this period. It is interesting to note the occurrence of biphasic curves of this type in the South American species *Haemagogus janthinomys* and *Psorophora ferox* (Kumm & Novis, 1938). In the case of nocturnal species such as *T. fuscopennatus*, the peaks occur after sunset and before dawn, and it is suggested that suitable conditions of low light intensity may play a part in stimulating activity. The term " eo-crepuscular " might be coined to describe a biting cycle of this type. These dawn and sunset peaks always tend to be variable, sometimes one or both failing to occur. The climatic relationship involved is probably a complex one and may differ in different cases.

Summary.

1. The work was carried out in Bwamba County, Uganda, a district where human yellow fever has recently occurred. It consisted mainly of 24-hour catches in banana plantations and rain forest combined with climate observations.

2. It was found that forest was cooler and moister by day than a banana plantation while the plantation was cooler and moister than the open air. By night, however, the climate of all three environments was strikingly similar.

3. Methods used in making 24-hour catches and large scale routine catches are described. Trials with trap nets showed these to be less efficient than hand catching.

4. Experimental catches showed that *Aëdes simpsoni*, the only species known to be a vector of yellow fever in Bwamba, bites mainly in coffee gardens, maize fields and the thinner parts and edges of banana plantations. It is scarce in fully exposed situations. It occurs within the edges of primeval rain forest. It prefers human blood to that of goats, fowls, and monkeys, and attacks the head and shoulders selectively.

5. It is shown that many forest mosquitos occur in banana plantations. Analysis of day and night catches suggests that they migrate into plantations from the forest by night. This finding is thought to have a bearing on yellow fever epidemiology.

6. The results of fifteen 24-hour catches in forest and 15 in banana plantations are analysed by four-hour groups, which correspond best with the successive climatic phases of the day and night. It is shown that there are two types of biting cycle. In the first there is one main peak of activity in 24 hours and this may occur either by day or by night. In the second, two peaks occur within 24 hours, usually about sunrise and sunset. It is suggested that these cycles are dependent on features of the microclimate, and the biting behaviour of the main species is discussed from this standpoint.

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References.

Dunn, L. H. (1926.) Mosquitos bred from dry material taken from holes in trees.—Bull. ent. Res., **17,** pp. 183–187.

——. (1927.) Tree-holes and mosquito breeding in West Africa.—Bull. ent. Res., **18,** pp. 139–144.

Edwards, F. W. (1941.) Mosquitoes of the Ethiopian Region. III. Culicine adults and pupae. London, Brit. Mus. (Nat. Hist.).

Gibbins E. G. (1942.) On the habits and breeding-places of *Aëdes* (*Stegomyia*) *simpsoni* Theobald in Uganda.—Ann. trop. Med. Parasit., **36,** pp. 151–160.

Haddow, A. J. (1942.) The mosquito fauna and climate of native huts at Kisumu, Kenya.—Bull. ent. Res., **33,** 91–142.

——. (1943.) Measurements of temperature and light in artificial pools with reference to the larval habitat of *Anopheles* (*Myzomyia*) *gambiae* Giles and *A.* (*M.*) *funestus* Giles.—Bull. ent. Res., **34,** pp. 89–93.

——. (1945). On the mosquitoes of Bwamba County, Uganda. I. Description of Bwamba with special reference to mosquito ecology.—Proc. zool. Soc. Lond., **115,** pp. 1–13.

Hopkins, G. H. E. (1936.) Mosquitoes of the Ethiopian Region. I. Larval bionomics of mosquitoes and taxonomy of Culicine larvae.—London, Brit. Mus. (Nat. Hist.).

Kerr, J. A. (1933.) Studies on the abundance, distribution and feeding habits of some West African mosquitos.—Bull. ent. Res., **24,** pp. 493–510.

KUMM, H. W. & NOVIS, O. (1938.) Mosquito studies on the Ilha de Marajó, Pará, Brazil.—Amer. J. Hyg., **27**, pp. 498-515.

MAHAFFY, A. F., SMITHBURN, K. C., JACOBS, H. R. & GILLETT, J. D. (1942.) Yellow Fever in Western Uganda.—Trans. R. Soc. trop. Med. Hyg., **36**, pp. 9–20.

PHILIP, C. B. (1930.) Studies on transmission of experimental yellow fever by mosquitoes other than *Aëdes*.—Amer. J. trop. Med., **10**, pp. 1-16.

REICHSAMT FÜR WETTERDIENST. (1937.) Aspirations-Psychrometer-Tafeln.—Berlin.

SHANNON, R. C. (1939.) Methods of collecting and feeding mosquitos in jungle yellow fever studies.—Amer. J. trop. Med., **19**, pp. 131–140.

NOTES ON *HELOPELTIS SANGUINEUS*, POPP., ON COTTON IN NIGERIA.

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In 1925, the writer (2) described some experiments that demonstrated the rôle of *Helopeltis* as a pest of cotton at Ibadan, Nigeria. Evidence was obtained that attack was greater on the improved indigenous Ishan *(Gossypium barbadense,* formerly described as *G. vitifolium)* than on either American Allen *(G. hirsutum)* or the ordinary native cotton *(G. peruvianum)*.

Since 1928, Ishan has been grown throughout the cotton-growing areas of the south-western part of Nigeria; *G. peruvianum* is still grown in the extreme north of the Oyo Province and in Ilorin Province. *Helopeltis* has become the major pest of cotton on Moor Plantation, Ibadan, where the Ishan is selected and multiplied before being distributed to farmers. Fortunately, the small native plots of cotton, with an average area of less than one acre, are seldom seriously attacked; although extensive damage occurred in 1929 on native plots near Okaka, about 40 miles north-west of Oyo. In 1924, *Helopeltis* was responsible for considerable damage to cotton on the Government Farm at Ilorin, and, in 1929, was the principal pest of that crop at Bode Sadu, a village some 14 miles south of Jebba.

Taxonomy.

In a previous paper (3), the writer mentioned the taxonomic difficulties presented by the genus *Helopeltis*. Orange and red individuals attacking cotton at Ibadan were identified in 1923 by the Imperial Institute of Entomology as *H. bergrothi*, Reut., and *H. sanguineus*, Popp., respectively. Recently individuals of both colourations have been identified as *H. sanguineus* and, as shown below, they have now been proved to belong to the same species.

There is a rare type of *Helopeltis* on cotton, characterised by having three bands of greyish colouration on the hemi-elytra. This was considered by Lean (5) to be a form of the common species (now known as *H. sanguineus)*. Recently, these banded specimens were shown to Mr. H. E. Box, who informed the writer that they were identical with the common cacao *Helopeltis* of the Gold Coast, which resembles *H. bergrothi* var. *rubrinervis*, Popp. Mr. Box has found that there are two species attacking cacao in the Gold Coast, the common ? *rubrinervis*, which has orange nymphs, and *Helopeltis* sp. near *bergevini*, which has green nymphs. The latter is the species Cotterell (1) recorded under the name of *H. bergrothi* as a minor pest of cacao in the Gold Coast. The writer (3) has pointed out that the adult illustrated by Cotterell differs in colouration from *H. bergrothi* adults found on cacao in southern Ibadan and Ondo Province in Nigeria.

Colour Variation.

Orange males and red females have frequently been seen *in coitu* in the field; the writer has not yet seen a red male. A small series of breeding experiments, carried out in 1942, proved that orange and red individuals belong to one species.

Of 18 females obtained from crosses between orange males and females, ten were orange and eight red; of 21 females from crosses between orange males and red females, eight were orange and thirteen red. It was found that, though some individuals were red immediately after ecdysis, many acquired the red colouration gradually during the first three days after moulting; the latter individuals were orange in colour after ecdysis.

Of 4,013 adults collected from two cotton plots between 10th August, 1942, and 1st May, 1943, 2,018 were orange males, 1,414 were orange females, and 581 were red females. As the collections were made on six days a week, it is evident that during the time freshly-moulted adults were present, about early September to early January, a number of the individuals recorded as being orange in colour had not had time to acquire red colouration. Of 1,052 females collected between 5th September, 1942, and 2nd January, 1943, 794 (75½ per cent.) were orange and 258 (24½ per cent.) were red; of 913 females taken between 3rd January and 1st May, 1943, 607 (66½ per cent.) were orange and 306 (33½ per cent.) were red. During the latter period, collections were made from cotton between 3rd January and 10th February (when the crop was uprooted) and from weeds in the two plots between 11th February and 1st May; of 427 females taken on cotton, 281 (66 per cent.) were orange and 146 (34 per cent.) were red; of 486 females collected on weeds, 326 (67 per cent.) were orange and 160 (33 per cent.) were red. It is evident that the ratio of orange to red females was not affected by the food-plants and that the true ratio is 2 : 1.

The series of breeding experiments carried out to date is too small to allow of any conclusions being made about the mode of inheritance of colour.

Food-plants.

Lean (5), who studied the bionomics of *Helopeltis* on cotton at Ibadan in 1925, records only two alternative food-plants, *Theobroma cacao* and *Psidium guayava,* and cites a record of the finding of adults by the writer on the hog-plum, *Spondias mombin* (syn. *S. lutea).* Field observations during the ensuing years have shown that *H. sanguineus* is more polyphagous than was suggested by Lean. Breeding has been observed on the following plants: *Spondias mombin, Solanum verbascifolium, S. torvum, Vigna unguiculata, Cajanus cajan, Mucuna aterrima, Psidium guayava, Jussiaea* sp. (probably *linifolia), Mangifera indica, Anacardium occidentale, Acalypha* sp. and *Paullinia pinnata.* In addition, adults have been seen feeding on: *Panax* sp., *Ricinus communis, Combretum racemosum, Lagerstroemia flos-reginae* and *Theobroma cacao.*

The writer has only once seen an adult on cacao at Ibadan, and suspects that it may have been the rare species (? *rubrinervis);* it was not the ornate *H. bergrothi* which occurs on cacao in areas south of Ibadan and in Ondo Province.

Seasonal Incidence.

The first migrants appear on cotton in the first week of August each year. Typical lesions are common on *Spondias mombin* during July, and it is probable that the majority of the migrants to cotton come from these plants. In early August there are still two cotton plants to a stand and their height is only about eight inches. Some of the female migrants are gravid, and the first nymphs appear on the cotton about a fortnight later. Adults and nymphs are abundant from mid-September to mid-December, after which nymphs are rare and adults rapidly decline in numbers; there appear to be three generations between early August and mid-December. In normal years conditions are unfavourable for *Helopeltis* in late December and January, as the cotton plants are producing few new shoots and the dry "harmattan" wind is blowing. In February, 1939, a number of adults (one pair of which were *in copula)* and a small nymph were found on *Jussiaea* sp. growing on the bank of a river bordering Moor Plantation; at that time nearly all the *Helopeltis* population had left a cotton field 400 yards from the river. White Livingston atmometers were set up on the river bank and in the cotton fields; it was found that evaporation was 40 per cent. less near the river.

In 1942-43, the Ishan selection plots on Moor Plantation were on land recently cleared from bush. By the time the cotton was uprooted (10th February, 1943, and 3rd March, 1944), numerous young plants of *S. mombin* and *Paullinia pinnata* had made their appearance; in early 1943, adults were fairly numerous on these plants up to early May, and a few nymphs were present during April. Breeding on the cotton ceased in early January and no nymphs were found during February and March.

During May and June, *Helopeltis* appears to be extremely rare; occasional adults are met with in the bush, and the only record of breeding at that time was on a very small scale on mango seedlings in a nursery. During July, adults become more numerous (on *S. mombin)*. All the breeding and feeding records for *Vigna, Mucuna, Cajanus, Solanum, Acalypha, Panax, Lagerstroemia, Jussiaea, Combretum, Ricinus* and *Psidium* were made between late September and mid-February, *viz.*, during the cotton season. Small scale breeding on *Anacardium* was observed once in the first half of August.

Incidence on Cotton at Ibadan.

There are considerable variations from season to season in the abundance of *Helopeltis*; in some years they appear in thousands and in others they are almost entirely absent. The following table shows the degree of infestation in 16 out of the last 22 cotton seasons; unfortunately no reliable data are available for the 1923-24, 1927-28, 1934-35; 1935-36, 1936-37 and 1937-38 seasons.

TABLE I.

Very Abundant ..	1939-40, 1943-44.
Abundant	1922-23, 1924-25, 1929-30, 1930-31, 1931-32, 1932-33, 1938-39, 1941-42, 1942-43.
Rare	1925-26, 1926-27, 1928-29, 1933-34, 1940-41.

The writer has been unable to find any correlation between the annual variations in the abundance of *Helopeltis* and climatic conditions. The mean annual rainfall at Ibadan for the 31 years from 1905-1935 was 50.5 inches; from 1936-1943 the annual rainfall was as follows: 39.72; 44.49; 40.74; 44.53; 44.43; 49.19; 39.45 and 42.00 inches. The unusually low precipitation of the last eight years may have been favourable to *Helopeltis*; but it is difficult to explain its almost complete absence from the 1940-41 cotton crop following the exceptionally heavy infestation of 1939-40. There were no peculiarities in the distribution of rainfall during 1940.

In early 1925, 1926, and 1927, the north-easterly " harmattan " wind was unusually severe, and *Helopeltis* was rare in two of the succeeding cotton seasons (and probably the third); but the heavy infestation of 1939-40 followed a moderately severe " harmattan."

The remaining seasons in which *Helopeltis* is known to have been rare, *viz.*, 1928-29 and 1933-34, were characterised by unusually heavy rainfall during the months of July, August, September, and October; the total precipitation for these four months was 33.53 inches in 1928 and 33.50 inches in 1933, as compared with a mean of 22.98 inches (based on the years 1905 to 1943). There was very little " harmattan " in early 1928 and 1933.

Mr. H. C. Doyne, formerly Senior Agricultural Chemist, kindly analysed soil samples taken on either side of a number of cotton plants, some of which were severely attacked by *Helopeltis* and others lightly attacked. The analytical results did not reveal any significant differences between the two groups of samples. During the course of our investigations, it was noticed that *Helopeltis* attack was particularly severe in a water-logged area. In addition, it was observed that attack was less severe on cotton following *Mucuna aterrima* than on that following either maize or yams; both the last-named crops retard the growth of the cotton plants during the early part of the season.

Control.

During the coming cotton season it is proposed to test the sweetened arsenical bait found by Kirkpatrick (4) to give promising results, on an experimental scale, against *H. bergrothi* on cinchona. As *Helopeltis* attack is largely confined to cotton on Moor Plantation, there are no practical difficulties in the employment of artificial control measures, which are unsuitable for use on the small native plots.

References.

1. Cotterell, G. S. (1928.) Minor pests of Cacao.—Bull. Dep. Agric. Gold Coast, no. 13, pp. 100–102.

2. Golding, F. D. (1925.) Observations on *Syagrus calcaratus*, F., and *Helopeltis bergrothi*, Reut., minor pests of cotton in Southern Nigeria.—4th Ann. Bull. Dep. Agric. Nigeria, pp. 82–88.

3. ——. (1941.) Capsid pests of cacao in Nigeria.—Bull. ent. Res., **32**, pp. 83–89.

4. Kirkpatrick, T. W. (1941.) *Helopeltis* (Hem. Capsidae) on Cinchona.—Bull. ent. Res., **32**, pp. 103–110.

5. Lean, O. B. (1926.) Observations on the life-history of *Helopeltis* on cotton in Southern Nigeria.—Bull. ent. Res., **16**, pp. 319–324.

INSECTARY REARING OF *ANOPHELES PHAROENSIS.*

By Major O. H. Theodor, R.A.M.C., and Staff/Sgt. B. T. Parsons, R.A.M.C.

A cage colony of *Anopheles pharoensis*, Theo., was established in September, 1943. The methods used were mainly those described by Hackett in his paper on the Malaria Station in Tirana, read at the Amsterdam Malaria Congress in 1938.

Description of Cage.

The cage used was a copy of the model described by Hackett with slight modifications. It was made of wood, measuring 60 by 60 by 100 cm. The top and an observation window in front were of glass. The back and the lower half of the sides were of plywood, and the upper halves of the sides were covered with mosquito netting. In the upper third of the front was a sleeve of mosquito netting for the handling of the mosquitos and the observation window. A big sleeve covered the whole of the lower third of the front for the introduction of the rabbit cage. The bottom was a zinc tray sloping to a screened hole for the collection of the rabbit urine. The rabbit was kept in a separate cage of mesh wire, which was introduced at night and removed in the morning. This arrangement made it easier to keep the cage clean than the original model, in which the rabbit cage was built in and kept closed by a slide door. A narrow shelf was fixed across the back half-way up the cage on which dishes containing sugar solution for egg-laying were kept. Humidity was maintained by covering the sides and front of the cage with a double blanket which was kept moist. During the summer, water had to be sprayed 3-4 times a day on the blanket and into the cage by means of a flit pump. No facilities for maintaining a constant temperature existed. Light entered the cage only through the glass top, and although the light intensity was rather low, it was sufficient to keep the mosquitos at rest during the day. Towards evening the " swarming light " was switched on for several hours. This consisted of a plate of dark blue glass put on top of the cage, behind which a 15-watt lamp was fixed in a cardboard box to avoid the escape of white light from the sides.

Adult Mosquitos.

Larvae of *A. pharoensis* were collected in various breeding places in the neighbourhood of Cairo, bred out in the laboratory, and the adults put in the cage the next day. They were fed on blood and sugar solution, the latter was first kept soaked in cotton wool in a Petri dish. Later a small sponge was soaked in the sugar solution and suspended from the ceiling of the cage. Males and females settled and fed readily on the sponge. Glucose, as well as ordinary sugar, was used, and both appeared equally attractive to the mosquitos.

At first a rabbit with the hair cut short at the back was used as a blood supply, but the mosquitos showed a marked reluctance to feed on it, and after it died, on 11th November, human blood was used, by putting the forearm into the cage at least once daily. The mosquitos bite readily at any time of the day, but most bites were obtained towards evening. When the population was about 200 females, 30-40 bites were obtained on the forearm in 10-15 minutes. Only single mosquitos fed after the first rush. The number of egg batches increased rapidly after human blood was offered. During September and October only 8-10 egg batches were obtained, while in November and December the figure increased to over 200.

Bite Reactions.

These varied in different persons. In some there was no immediate reaction after the bite, but 12-24 hours later, the bites began to itch and papules sometimes appeared which slowly subsided. In others, an immediate wheal appeared, which disappeared after 15-20 minutes. In one person the wheals were transformed into reddish papules, which persisted for several days and itched violently. In one case, the delayed reaction changed over into an immediate wheal reaction after several weeks. The reactions described are in accord with those observed in the case of other biting insects. The delayed reaction is the initial form. As the interval between the bite and the appearance of the papule becomes shorter, the itching and inflammation becomes more intense, until the reaction changes into an immediate wheal reaction. This persists for a long time, until de-sensitisation has been reached with nearly complete absence of reaction except for slight itching. The reactions observed indicate that the different persons were at different stages of sensitisation at the beginning of the exposure to bites, apart from the fact that individuals differ considerably in the intensity of their reactions.

Swarming.

During the day the mosquitos rested mainly at the sides in the upper part of the cage and on the wooden parts of the ceiling. As soon as the blue light was switched on, swarming began. A number flew up against the light and beat against the glass. They then settled down to zig-zag movements at about the same level below the light. This was observed at different levels, but mainly at 10 to 40 cm. below the glass. Rising and falling movements were also observed, but eventually the mosquitos settled down again to a horizontal zig-zag course. The lower parts of the cage could not be observed accurately as the light was too dim, but some mosquitos were observed dancing there. Males were seen to seize a flying female and drop out of the swarm. Sometimes mosquitos were observed swarming at dusk before the blue light was switched on. If a white light was substituted for the blue, swarming ceased rapidly and the mosquitos settled down at the sides.

During the second half of October, the population of the cage was 40-50 and swarming was not very lively. When on 31st October 260 mosquitos were introduced, swarming began immediately. This seems to indicate that a minimum density of population is required for swarming.

Egg-laying.

Petri dishes with river water were placed on the shelf and egg batches removed every morning. From 6th-25th November, a piece of a green filamentous alga was put in the middle of one dish and the other was left with water only. Out of 87 batches laid during this period 55 or 65 per cent. were found in the dish containing algae. This preference for the dish with algae may be due to smell or to the fact that the algae provide a more comfortable resting place. Egg-laying was not observed during the day-time. Batches were found either along the edge of the dish or adhering to the algae. The number of eggs in a single batch varied from 60-150 with an average of 100.

For hatching, the dish was covered to avoid dust settling on the water, and the lid was supported by a piece of plasticine to allow circulation of air. Hatching was uniform as a rule, and most of the larvae hatched within one or two days. The egg period lasted three or four days in November at a mean temperature of 21° C.

Nearly all egg batches were fertile, and the percentage of larvae hatching was about 70 per cent. for the first 25 batches in which accurate counting was carried out. The percentage varied, however, from 35 to 95 per cent.

Larvae.

At first great difficulty was encountered in breeding the young larvae through to the adult stage. Sometimes a whole batch died in a day. This was due to dust storms and in some cases probably to the varying chlorine content of the tap water. The bowls containing the larvae were then kept covered with glass supported by plasticine on the rim to allow circulation of air and evaporation, and the tap water was replaced by Nile water or water from natural breeding places. Mortality was generally heaviest in the first stage, particularly in very large lots (1,000-2,000 eggs). The optimum density of population was found to be 100-150 first- or second-stage larvae and 50 third- and fourth-stage larvae in a bowl of 15 cm. diameter.

Experiments were then carried out to determine optimum conditions, and the following parallel series of three bowls each were put up with 50 larvae in each bowl. Nile water was used throughout.

(a) Nile mud and powdered Army biscuits.
(b) Nile mud, Army biscuit, and baker's yeast.
(c) Algae from a natural breeding place.
(d) Algae, baker's yeast.
(e) Algae, powdered biscuit, and baker's yeast.

In series (c) and (d) the larvae all died before pupation. In all the bowls containing powdered biscuit they developed well and 70-80 per cent. of second-stage larvae pupated. The addition of yeast did not increase the percentage of pupation, but the majority pupated after 11-12 days at a mean temperature of 28-29° C., while in the series without yeast the majority pupated after 14 days. Yeast, however, is a valuable food for the first-stage larvae. No difference was observed between the series in which mud was used or that with algae (powdered biscuit in both). The following technique was then adopted. About 100 first-stage larvae were put into a white enamel bowl of 15 cm. diameter, which contained a layer of Nile mud of about one cm. depth and Nile water to about four cm. depth. This was kept covered as described above. The larvae were fed daily with a few drops of a thin suspension of baker's yeast in water. When the larvae had reached the second-stage, a small amount of finely-ground Army biscuit was sprinkled on the surface. Care had to be taken not to give too much biscuit powder, and only so much was given that the larvae could keep the surface clean during the day. An indication that the surface was clean was the fact that the powder spread rapidly like an oil film, covering the whole surface of the bowl. When the larvae grew, powder was added more often, sometimes three or four times a day. If mortality had not reduced the number, larvae were removed until only 50 fourth-stage larvae remained. The bowls were put into the sun daily from 08.30-16.00 hours, except during dust storms. The larvae were found to prefer the shaded side of the bowl, particularly during the middle of the day. The temperature of the water never rose much above 30° C., due no doubt to the intense evaporation and the constant breeze. The light probably influenced favourably the growth of diatoms and infusoria, on which the larvae feed. *Paramecium* often appeared in large numbers, and in some bowls the larvae became covered with *Vorticella* and allied forms. This did not impede their growth and pupation. Larvae were seen nibbling at others, apparently feeding on the Protozoa and biting off the other larvae's hairs. Full-grown larvae were as big as those occurring in their natural habitat. Their colour was a pale greyish brown as a rule; none of the bright green larvae observed commonly in nature were seen. This supports the view that the green larvae derive their colour from the chlorophyll of water-plants and algae. The characteristic white markings did not appear regularly but were more marked in some batches than in others. In one batch a continuous white stripe along the thorax and abdomen was observed in most specimens.

No exact data could be collected on the duration of the larval period, as no facilities existed for maintaining a constant temperature. When the temperature became lower in December, the larvae were kept in an incubator overnight. This was kept at 23° C. at first, and then raised to 27° C. At 23° C. (at night) the larval period was about 23 days, and at 27° C. about 18 days. This rather long duration of the larval period at these temperatures indicates that the optimum temperature for *A. pharoensis* is much higher. No calculations are given as the data are insufficient.

Pupae.

These were removed every morning and kept in a bowl inside a cage until they hatched. The adults were left for 24 hours in the hatching cage and then either put into the mating cage or used for experiments. Only very few pupae failed to hatch. The pupal period lasted 3-4 days at 20° C.; the adults hatching from these pupae were as big and vigorous as those found in natural habitats.

Discussion.

A colony of *A. pharoensis* was maintained for three generations. Omitting the first period from 7th September to the beginning of November, the generations were as follows:

1st Generation	4th November, 1943 to 22nd November, 1943.
2nd ,, ...	23rd November, 1943 to 22nd December, 1943.
3rd ,, ...	23rd December, 1943 to 30th January, 1944.

Up to the 22nd November, 1943, the adults were obtained from collected larvae; from the 23rd November onwards, only laboratory-bred adults were used. The following numbers were bred:

7th September, 1943 to 22nd November, 1943 ..	1,038 males	1,106 females.
23rd November, 1943 to 31st January, 1944 ..	1,126 males	1,081 females.

From the beginning of November, 200-300 adults hatched every week until the first week in January, 1944. Thirty-one egg batches were laid in the week 10th-16th December, 1943, and only six the next week. After that, egg-laying decreased rapidly and the last batch was obtained on 19th January, 1944. Mean temperatures in the insectary were:

August	30.4° C.	November ..	21° C.
September ..	28.5° C.	December ..	17° C.
October ..	28.2° C.	January	13.7° C.

Attempts to raise the temperature sufficiently by means of an oil stove were unsuccessful, particularly as the stove could not be kept burning overnight for safety reasons.

During the first 6-7 weeks, the breeding was not very successful, mainly because the mosquitos did not feed well on the rabbit, partly because the population was probably too small to induce swarming and partly because a number of technical details had not been sufficiently worked out.

With the introduction of a big batch of mosquitos on 31st October, 1943, and the beginning of feeding with human blood, the colony began to thrive, and only the onset of cold weather and the lack of facilities for maintaining a constant optimum temperature brought it to an end.

The following rough calculation gives an indication of the potential production of the cage.

In the six weeks from 1st November, 1943, to 16th December, 1943, 1,200 females produced 220 egg batches. On a basis of an average of one hundred eggs per batch this would give 22,000 eggs. Allowing for a mortality of 30 per cent., this represents approximately 15,000 first-stage larvae. Of these only about 50 per cent. reach adult stage, giving 7,000 to 8,000 mosquitos, or 3,500 to 4,000 females.

These figures could probably be much improved under better conditions.

TABLE I.

	Period. Weeks beginning and ending	Adults hatched		No. of egg batches
		Males	Females	
—	17 September–4 November ..	862	931	12–15
First generation ..	5–25 November*	307	312	100
Second generation ..	26 November–23 December ..	511	590	122
Third generation ..	24 December–3 February ..	384	366	15

* The rabbit died on the 11th November, and subsequent to that date the mosquitos were fed on human blood.

DESCRIPTIONS OF NEW LARVAE AND PUPAE OF ETHIOPIAN CULICINI.

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Culex (subgenus Mochthogenes). (figs. 1, 2).

In the subgenus *Mochthogenes,* only the pupa of *Culex (M.) inconspicuosus,* Theo., has been described. Since one of us (M.P.) has obtained the immature stages of all the known species, including *C. (M.) castor,* De M., we take advantage of this opportunity to give a key to the pupae. The pelts were all obtained from specimens bred in isolation at Yangambi, Belgian Congo, and the resulting adults identified by means of the male terminalia.

The terminal hairs of the paddle appear to be absent in the pelt of *C. (M.) castor,* but this may be due to accident, although no scars are to be seen.

Key to the Pupae.

1. Paddles pointed apically, denticulated terminally; ? without terminal hairs on the paddle (fig. 2f). Trumpets and seta VIII "A" as figured (fig. 1b, m) *castor,* De M.
   Paddles evenly rounded apically, smooth; terminal hairs present 2
2. Accessory paddle hair much shorter than the principal hair; trumpet with broad sub-median dark band, apex slightly infuscated (fig. 1d) *inconspicuosus,* Theo.
   Paddle hairs more or less subequal (fig. 2e) 3
3. Seta "A" on segment VIII with 7 divided or subplumose branches (fig. 1k); trumpet with apex slightly widened (fig. 1a) ......*simpliciforceps,* Edw.
   Seta "A" on segment VIII with 4 simple branches (fig. 1l); trumpet of more or less even width throughout (fig. 1c) segments VII and VIII darker than other segments ....*fimbriforceps,* Edw.

Key to the Larvae.

1. Subventral tufts plumose; comb of spine-like scales and scales (fig. 1h) *inconspicuosus,* Theo.
   These tufts simple; comb of definite scales only 2
2. Pecten of about 7 long, narrow spines, widely set distally; upper caudal seta single (fig. 1o) ....*fimbriforceps,* Edw.
   Pecten of 10 or more closely set, broad but shorter spines; upper caudal seta double 3
3. Comb with about 30 scales ....*simpliciforceps,* Edw.
   Comb with more than 40 scales ....*castor,* De M.

Culex (Mochthogenes) fimbriforceps, Edwards (fig. 1, o).

Larva. Seven pelts from Yangambi, Belgian Congo *(Parent)*.

Head.—Antenna spiculate, dark throughout, but sometimes paler medianly; generally darker than in the other species of this subgenus. Tuft at about $\frac{3}{4}$ consisting of about 29 plumose branches. Seta "A" with about 8 plumose branches; Seta "B" short, not reaching the anterior border of the head, with about 5 branches; Seta "C" with 2-4 branches, smaller than "B" and placed immediately behind "B"; Seta "d" small and delicate. Mentum with 1 central tooth and 6 teeth on each side; broader than long.

Abdomen.—Comb a patch of about 40 narrow scales, the proximal row being smaller in size than those in the distal row. Siphon (fig. 1, o) pale, but with a darkened median band in one specimen examined. Siphonal index varies in the specimens examined from 4.6-6.0. Pecten of 8 narrow spines with small denticles along the whole of the ventral edge. The pecten spines are widely set, especially the apical ones, but they do not reach to the middle of the siphon. There are 5 pairs of subventral tufts each with 3 simple branches. All the sub-ventral tufts are at least twice the diameter of the siphon at the point of attachment, and none of them are situated proximal to the pecten. Anal segment with complete saddle which bears small spines distally. Upper and lower caudal setae both single. Lateral seta 4-branched, much shorter than the saddle. Ventral brush composed of 4 pairs of 6-branched tufts. Gills missing.

Culex (Mochthogenes) castor, De Meillon (fig. 1, e, f).

Larva. One pelt from Yangambi, Belgian Congo *(Parent)*.

Head.—Antenna spiculate and slightly infuscated at base and beyond tuft. Tuft at about 4/5 consisting of about 22 plumose branches. Head seta "A" with 10 plumose branches; seta "B" with 3 simple branches, reaching the anterior margin of the head, which, however, is greatly flattened in the specimen examined. Setae "C" and "d" missing. Mentum with a large central tooth and 5 smaller teeth on each side of the central one.

Abdomen.—Comb (fig. 1f) a patch of about 40 narrow scales of 2 sizes, and fringed apically only. The distal scales are longer and broader apically than the proximal ones. Siphon (fig. 1e) somewhat infuscated apically; index 4.3. Pecten (fig. 1e) of 13-14 large closely set spines with denticles along the entire ventral edge. The pecten spines do not reach to the middle of the siphon. There are 5 pairs of subventral tufts each tuft consisting of three simple branches. The subventral tufts are slightly longer than the diameter of the siphon at the point of attachment. Anal segment with complete saddle. Upper caudal seta 2-branched, the upper branch being approximately half the length of the lower branch. Lower caudal seta single. Ventral brush missing but the scars of 5 pairs of tufts can be seen. Lateral seta small, 4-branched. Gills missing.

Culex (Mochthogenes) simpliciforceps, Edwards (fig. 1, g, n).

Larva. Five pelts from Yangambi, Belgian Congo *(Parent)*.

Head.—Antenna spiculate. Tuft at about 7/9 (well over 2/3) consisting of 26 sparsely plumose branches. Head seta "A" with about 8 plumose branches; seta "B" with 4 branches which do not reach the anterior border of the head; seta "C" simple, with 1-2 branches about as long as "B"; seta "d" small, delicate, single. Mentum with 5 teeth on each side of the central tooth which is not much longer than the lateral teeth.

Abdomen.—Comb (fig. 1g) of about 24 narrow scales which are fringed apically. Siphon (fig. 1n) sometimes with a well-marked median dark band, and with index 4.1. Pecten of 10 closely set spines with delicate denticles along the whole ventral side. The pecten spines do not reach the middle of the siphon. There are five pairs of sub-ventral tufts each with 3 simple branches, some of which are $1\frac{1}{2}$ times the diameter of the siphon and others just a little more than the diameter of the siphon at the point of attachment. Anal segment with complete saddle, the distal portion of which is slightly spiculate. Upper caudal seta 2-branched, the upper branch being about $\frac{1}{2}$ the length of the lower branch. Lower caudal seta single. Lateral seta very near the distal margin and with 4 branches which are very short and slender. Ventral brush with about 6 pairs of tufts, one of which appears to be proximal to the barred area.

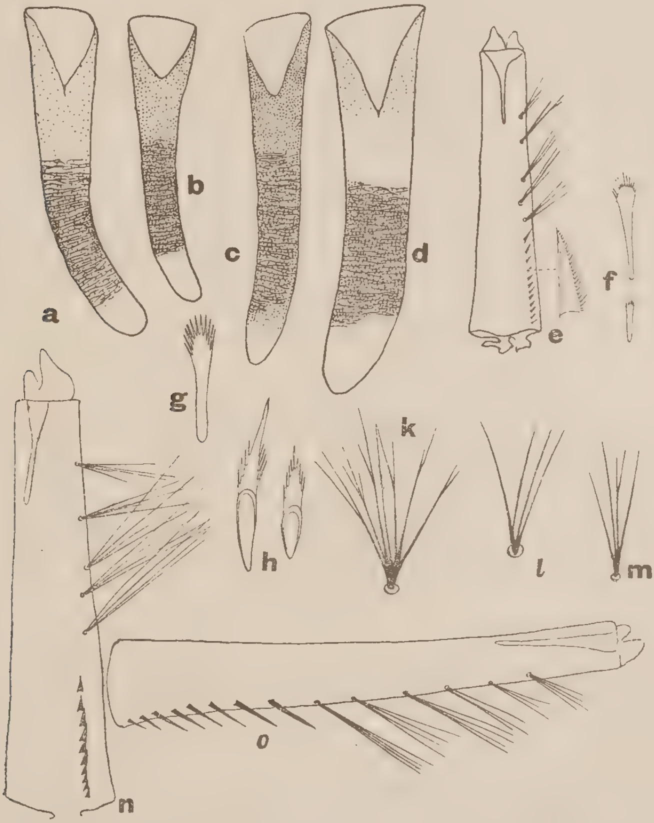

Fig. 1.—*Culex* (*M.*) *simpliciforceps*, Edw.: *a*, trumpet of the pupa; *g*, comb scale of the larva; *k*, seta VIIIA of the pupa; *n*, siphon of the larva.—*Culex* (*M.*) *castor*, De M.: *b*, trumpet of the pupa; *e*, siphon and pecten spine of the larva; *f*, comb scales of the larva; *m*, seta VIIIA of the pupa.—*Culex* (*M.*) *fimbriforceps*, Edw.: *c*, trumpet of the pupa; *l*, seta VIIIA of the pupa; *o*, siphon of the larva.—*Culex* (*M.*) *inconspicuosus*, Theo.: *d*. trumpet of the pupa; *h*, comb spines of the larva.

Culex (Mochthogenes) inconspicuosus, Theobald (fig. 1, h).

Note on the Larva.—Hopkins, 1936 (Mosquitos Ethiop. Reg., Part 1, p. 189), states that the comb of *C. inconspicuosus* is composed of scales, one of which is figured by him. We, however, have found both in South African and Belgian Congo material that the teeth are more spine-like.

Culex (Neoculex) wigglesworthi, Edwards (fig. 2, a, b, c).

Larva. One pelt from Yangambi, Belgian Congo *(Parent)*.

Head (fig. 2b).—Antenna spiculate. Tuft of 27 plumose branches at about $\frac{3}{4}$. Head seta "A" with 6-7 plumose branches. Setae "B" and "C" 2-branched, plumose, and very long. Seta "d" single. Setae "e" and "f" each with about 9 short branches. Mentum with 7 teeth on each side of the central tooth.

Abdomen.—Comb (fig. 2a) a patch of about 45 narrow scales of two sizes, the proximal scales being shorter than the distal scales. Siphon (fig. 2a) with an index of 6.9. Pecten of 11 spines each with 4-5 denticles extending along the whole ventral edge of the spine (fig. 2a). Subventral tufts missing but the scars of 4 pairs present on the siphon. Anal segment with complete saddle. Upper caudal seta 4-branched with 1 long and 3 short branches. Lower caudal seta single. Ventral brush missing but the scars of 6 pairs of tufts can be seen. Lateral seta of 4 simple, short branches. Gills missing. The apical edge of the anal segment is spiculated.

This species resembles *C. (N.) rima,* Theo., very closely, but differs as follows:

Comb of *wigglesworthi* of about 45 scales, and comb of *rima* of about 70 scales. Siphon of *wigglesworthi* with index 6.9 and that of *rima* with index 8-9. Four pairs of subventral tufts in *wigglesworthi* and 2-3 pairs in *rima.* Lateral seta of *wigglesworthi* is 4-branched, and 2-branched in *rima.* Apex of anal segment of *wigglesworthi* spiculated and that of *rima* almost smooth.

Pupa. One pelt from Yangambi, Belgian Congo *(Parent)*.

This pupa is very easily distinguished from all other known Culicine pupae by the shape of the trumpet which is swollen at the middle and pointed at the apex. The tegument is light brown except for the paddles which have no special markings.

The trumpets are swollen in the middle and pointed at the apex. The ratio of the meatus: trumpet=1:1.1. There is a small aperture at the edge of the pointed apex of the trumpet. The basal half of the trumpet is tracheoid and the distal half is reticulate (fig. 2c). The general colour of the trumpet is blackish, the reticulate portion being darker than the basal portion.

Dorsal hair 2-branched. The other cephalothoracic hairs are not developed to any extent (2-4 branches). "O" is 2-branched and frayed; "P" bifid as long as "O"; "R" 4-branched $\frac{1}{2}$ the length of "O." The dendritic float hair has 9 main branches which are divided into many secondary plumose branches. "L" is a little tuft of 4-5 branches and "M" is a tuft of 4 small branches; "M" is situated just behind "L"; "S" is single, long and simple; "T" is 2-branched, much shorter than "S"; "U" single, slender and short.

Abdominal Hairs.—"B" is double and specially well developed on segments IV and V, being slightly longer than the segment. "C" II is a small tuft. "C" III is 5-branched and half the length of "B." "C" IV has 4-5 branches, a third the length of "B." "C" V-VI are 3-branched, and a third the length of "B." "A" VII is 3-branched, simple and nearly as long as "A" VIII. "A" VIII is a brush of 6 simple branches, $\frac{1}{4}$ the length of the paddle. "A" VIII is 2-branched and slightly shorter than "A' " VIII. Paddles normal, with accessory hair shorter than principal hair.

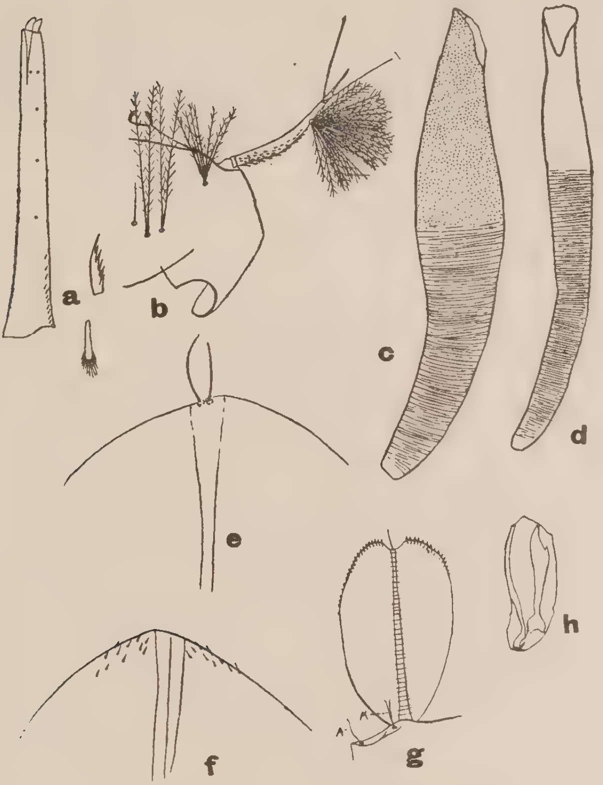

FIG. 2.—*Culex* (*N.*) *wigglesworthi*, Edw. : *a*, siphon, comb scale and pecten spine of the larva ; *b*, head of the larva ; *c*, trumpet of the pupa.—*Culex* (*N.*) *rima*, Theo. : *d*, trumpet of the pupa.—*Culex* (*M.*) *simpliciforceps*, Edw. : *e*, apex of the paddle of the pupa.—*Culex* (*M.*) *castor*, De M. : *f*, apex of the paddle of the pupa.—*Hodgesia cyptopus*, Theo. : *g*, paddle of the pupa ; *h*, trumpet of the pupa.

Culex (Neoculex) rima, Theobald (fig. 2, d).

Pupa. One pelt from Yangambi, Belgian Congo *(Parent)*.

This pupa is easily recognisable by the trumpets, which are long and thin (10 times as long as wide). Just before the opening there is a narrowing of the sides of the trumpet preceded by a light swelling. The aperture is small. The basal 2/3 of the trumpet are tracheoid and the terminal 1/3 is reticulate. Ratio of meatus: trumpet=1:1.1 (fig. 2d).

Dorsal hair with 2 branches, 1/3 the length of the trumpet; seta "O" is 2-branched, pectinate; "P" is 2-branched; "R" has 3-4 branches; "O" is equal in length to "P."

Float hair well developed, dendritic, with about 8 main branches. "H" single, short; "K" single, long; "L" weak, apex branched; "M" short, tufted; "S" single, long; "T" 2-branched, half the length of "S."

Hair "C" II is a small tuft. "C" III-VI with 3-5 branches, half the length of the segment. "B" IV-V with 2 branches, simple. "B" VI single. These hairs are longer than the segments. "A" VII 2-branched, simple; "A" VIII 3-branched, sometimes bifid apically, sparsely plumose; "A′" VIII 2-branched, short. Paddles pale with an accessory hair present.

Culex (Culex) striatipes, Edwards (fig. 3, a, d, e).

Larva. Two pelts from Livingstone, N. Rhodesia *(Muspratt)*.

Head (fig. 3a).—Antenna strongly spiculate, very dark brown beyond tuft; tuft at about 2/3 consisting of 28 plumose branches; head seta "A" with eight strong, plumose branches; seta "B" single or double, long, strong and plumose; seta "C" 2-branched, plumose, as well developed as "B"; seta "d" single, simple; setae "e" and "f" small, branched. Mentum with one central tooth and 5 teeth on each side of the central one.

Abdomen.—Comb (fig. 3d) of 10-14 spines of 2 distinct sizes, the ones in the proximal row being much smaller than those in the distal row. All the spines are heavily fringed basally. Siphon (fig. 3d) more or less straight-sided; apical half infuscated. Siphonal index 10.6. Pecten (fig. 3d) of 8 spines which are simple or with 1 small basal denticle. The spines are slightly curved and placed at increasing distances from one another. There are five subventral tufts which are small and single the most proximal tuft being placed proximal to the last pecten spine. Anal segment with complete saddle. Upper caudal seta double, one branch shorter than the other. Lower caudal seta single. Lateral seta missing. Ventral brush composed of 6 pairs of tufts each with 9 branches which are simple. Gills missing.

This species resembles *C. (C.) grahami,* Theo., but can be separated from it by the following differences:

Comb of *striatipes* has 14 spines of 2 distinct sizes and the spines are heavily fringed, whereas the comb of *grahami* consists of 20 spines which are uniform in size and delicately fringed. Siphonal index of *striatipes* is 10.6, and that of *grahami* is 12-15. The pecten spines of *striatipes* are placed at increasing intervals on the siphon and those of *grahami* are evenly spaced.

Pupa. Two pelts from Livingstone, N. Rhodesia *(Muspratt)*. (One pelt with paddles missing.)

Pale brown in colour except for slight infuscations on the trumpets. Characterised by the trumpets which are long and thin with the apices clearly enlarged. The opening of the trumpet is terminal. There is a broad sub-basal dark band which envelopes the tracheoid portion and the extreme apex is slightly infuscated. Ratio of length: breadth at the middle of the trumpet=17:1 (fig. 3e).

Abdominal hairs in general inconspicuous and poorly developed except for hairs "B" IV-VI and hair "S." Dorsal hair small, 5-branched; "O" and "P" very short with 3-6 branches; "R" with 1-3 branches and some distance from "P"; "H" and "K" close together and consisting of 1 and 6-8 branches respectively; "S" long and single; "T" double, half the length of "S"; "U" single and short.

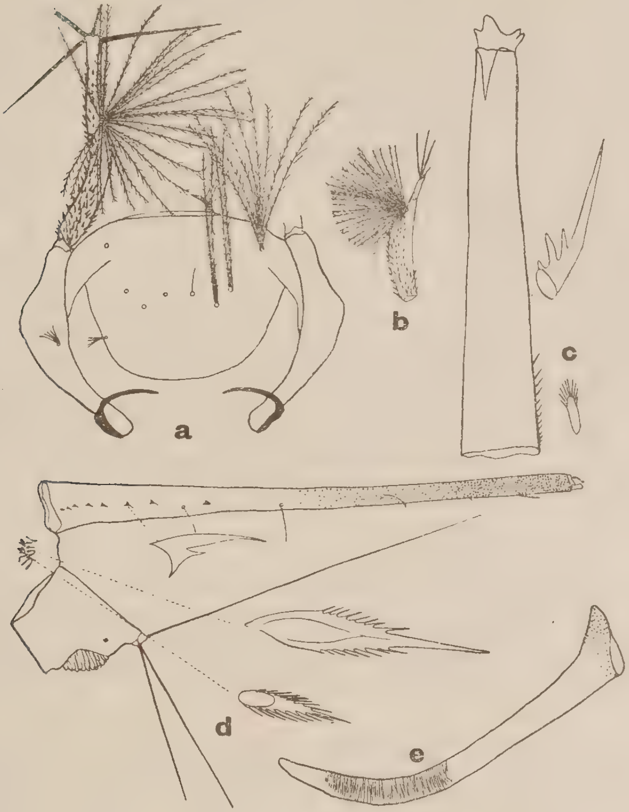

FIG. 3.—*Culex striatipes*, Edw. : *a*, head of the larva ; *d*, siphon, pecten spine and comb spines of the larva ; *e*, trumpet of the pupa.—*Culex telesilla*, De M. : *b*, antenna of the larva ; *c*, siphon, comb scale and pecten spine of the larva.

Float hair weak, small and with 5-6 main branches. "B" IV-VI double, about as long as the segment. "C" II-VI with 3-7 branches, poorly developed. The other hairs are short and inconspicuous; "A" VII 4-branched; "A" VIII with 7 short branches sparsely plumose; "A′ " VIII with 2-3 short branches. Paddles pale, rounded, midrib developed. One small, delicate terminal hair. Accessory hair apparently absent.

Culex (Culex) telesilla, ∠ De Meillon & Lavoipierre (fig. 3, b, c). ∠ sp. n. ×

Larva. Seven pelts from Yangambi, Belgian Congo *(Parent)*.

Head.—Antenna (fig. 3b) spiculate, very broad as far as tuft and then tapering very suddenly. Infuscated at extreme base and beyond tuft. Tuft at about 2/3, consisting of 27 to 33 plumose branches. Head seta "A" with 6 plumose branches; "B" and "C" as long as "A" and both with 2 plumose branches; seta "d" fairly long, single. Mentum with 7 smaller teeth on each side of the central tooth.

× cf. J. ent. Soc. Sthn Afr. 10 1947 p. 110.
also correspondence with De M.

Recorded D.O.P.

Abdomen.—Comb (fig. 3c) of about 24 small, narrow scales. Siphonal index varies from 4.6-5.6 (fig. 3c). Pecten of 10-14 spines, some of which have 3 basal denticles and some only 1 (fig. 3c). There are five pairs of subventral tufts each tuft having 4-6 simple, short and inconspicuous branches. The subventral tufts are shorter than the diameter of the siphon. The first pair of tufts lies proximal to the last 3-4 pecten spines. Anal segment with complete saddle. Upper caudal seta with 2-4 branches, one of which is always long. The short branches are just over ¼ the length of the long branch. Lower caudal seta single. Lateral seta minute with 4-6 branches. Ventral brush composed of 6 pairs of tufts each with about 9 branches (9-11). Gills missing.

This species is closely related to *C. (C.) perfidiosus*, Edw., but differs in the following respects: The antenna of *telesilla* is very much broader before the tuft than that of *perfidiosus* and it tapers very suddenly after the tuft which is not so in *perfidiosus*. It is infuscated at the base and beyond the tuft in *telesilla*, and in *perfidiosus* it is slightly infuscated only beyond the tuft. Head seta "A" in *telesilla* has 6 plumose branches, and in *perfidiosus* it has 10 plumose branches. The siphonal index of *telesilla* varies from 4.6-5.6, whereas the siphonal index of *perfidiosus* is about 6.5. Subventral tufts of *telesilla* have 4-6 branches and those of *perfidiosus* have 3-4 branches. In *telesilla* the first pair of subventral tufts is situated proximal to the last 3-4 pecten spines and in *perfidiosus* the subventral tufts are all placed distal to the pecten spines.

Pupa. Seven pelts from Yangambi, Belgian Congo *(Parent)*.

The main distinguishing characteristics are: (i) Hair "B" on segments V and VI which are long, stout and sub-plumose; (ii) hair "S" which is well developed in comparison with the other hairs on this segment; and (iii) hair "A" VII which is a plumose tuft.

Pupa light brown except for the trumpets, portions of the wing cases, and median, apical and basal areas of abdominal segments I-VI which are dark. Trumpets darkened and of medium length. Approximately, basal half tracheoid and darker than the rest. Distal part reticulate. Opening lateral. Ratio of meatus: trumpet=1:1.3.

Dorsal hair delicate with 7 branches. "O" with 5-6 long branches; "P" 2-branched, simple and slightly longer than "O"; "R" slightly separated from "P" and with 5 simple branches the same length as "O."

Float hair dendritic with about 11 main branches. "K" 2-branched, long; "H" single or bifid and ¼ the length of "K"; "L" and "M" small tufts; "S" very long, single and stout; "T" with 2-3 branches; "U" small, bifurcated or single. Cuticle immediately behind the float hairs is reticulated. Hair "I" on segment II has 1-2 long branches (the length of "S"), and on segments III-VII, hair "I" has 4-5 short, delicate branches; "B" II is 2-branched, shorter than hair "I"; "B" III with 2 branches more than half the length of the succeeding segment; "B" IV with 5 pectinate branches, longer than the segment and longer than "B" III; "B" V and VI with 2 stout branches, pectinate and longer than the segment; "B" VII very short and single (1/3 the length of the segment). Hair "C" on segments II-VI is branched and about half the length of the succeeding segment; "C" VII is smaller and more delicate; "A" VII with 4-5 plumose branches, nearly as long as "A" VIII; "A" VIII has 8 strongly plumose branches; "A′" VIII has 5-6 simple branches which are half the length of "A" VIII. Paddles pale, rounded, midrib developed but slightly fainter towards the apex. Paddle with a main and an accessory hair which are more or less equal in length.

The main hair is single; the accessory hair may be single, divided or bifurcated and is sometimes shorter than the main hair. (These variations may occur on one one side only.)

Culex (Culex) andersoni var. **bwambanus,** Edwards.

Pupa. Fifteen pelts from Cathedral Peak, Natal *(De Meillon)*.

Differs from *C. (C.) andersoni,* Edw. (Mosquitoes Ethiop. Reg., 1941, Part 3, p. 422), chiefly by the stippled aspect of the first abdominal segments (as is seen in *C. duttoni,* Theo.) and by hair "B" IV which is consistently double. (Single in *C. (C.) andersoni,* Edw.).

Trumpets and area between them darkened. Metathorax and segments I-VII darkened medianly. Stippling very pronounced between the float hairs. Trumpet like that of *andersoni*. Ratio of meatus: trumpet=1:1.4. Aperture of trumpet lateral. Dorsal hair long and double. "H" short, single; "K" with 1-2 branches, slightly plumose and long (4 times as long as "H"); "L" and "M" small, with 3-6 branches; "S" and "T" long with 1-3 branches; "U" single, short. Abdominal hair "B" sub-plumose or pectinate; "B" IV always double, sub-plumose; "B" V-VI single ("B" V was double on one side in 4 specimens examined). Hair "B" on segments IV-VI of equal length. Hair "C" on all segments as in *andersoni*. "A" VII with 3-4 plumose branches; "A' " VIII is single and equal in length to "A" VIII which has 8-9 plumose branches. Paddle pale, rounded, midrib developed. Principal hair of the paddle single, long (1/9 length of paddle) and often bifid or trifid. Accessory hair 1/3 the length of the principal hair.

Aëdes subgenus Diceromyia.

KEY TO THE PUPAE.

1. Hair of paddle with at least 5 branches (5-10) ....*flavicollis,* Edw.
   Hair of paddle single (rarely double) 2

2. Float hairs with branches finely pectinate 3
   Float hairs with apices of branches tufted 4

3. Dorsal seta short, about ½ the length of the trumpet; abdominal segments I-III and area between trumpets pale ....*adersi,* Edw.
   Dorsal seta much longer; abdominal segments I-III and area between trumpets infuscated ....*taylori,* Edw.
   furcifer, Edw.

4. Paddle hair simple; paddle pointed apically ....*zethus,* De M.
   Paddle hair double; paddle evenly rounded ....*fascipalpis,* Edw.

This key is based on the examination of the pupal pelts of *Aëdes (Diceromyia) fascipalpis* (five pelts from Livingstone *(Muspratt); furcifer* (four pelts from Rolle, Transvaal *(De Meillon); zethus* (12 pelts from Livingstone *(Muspratt); adersi* (one pelt from Tzaneen, Transvaal *(De Meillon)*; and *taylori* (15 pelts from Livingstone *(Muspratt)*; as well as from the descriptions by Edwards (Mosquitoes Ethiop. Reg., 1941, Part 3) of the pupae of *furcifer* (p. 401), *fascipalpis* (p. 402), and *flavicollis* (p. 401).

Unfortunately we have only been able to examine one damaged pelt of *adersi* (hair of the paddle missing). It is possible that the character of the terminal hairs of the paddles of *adersi* and *fascipalpis* would make differentiation of these two species much easier. This hair in *fascipalpis* has two branches which is unusual.

There are no reliable differences to separate the pupae of *taylori* and *furcifer*.

Aëdes (Aëdimorphus) yangambiensis, De Meillon & Lavoipierre (fig. 5, a, b, c).

Larva. Two pelts from Yangambi, Belgian Congo *(Parent)*.

Head.—Antenna spiculate, about half length of head. Tuft situated at about ½ consisting of 14 sparsely plumose branches. Head seta "A" with 10 plumose branches; "B" with 4 sparsely plumose branches; "C" appears to be 5-branched and "d" is missing. Mentum with 15 small teeth on each side of the central tooth.

Abdomen.—Comb (fig. 5a) a patch of 15 pale, short, broad scales. The specimen examined was slightly flattened but the siphon appeared to have slightly convex sides. Siphonal index 2.8 (fig. 5a). Pecten (fig. 5a) of 16 spines, heavily pigmented and with 1 or 2 basal denticles, the proximal spines having one large basal denticle and sometimes a second smaller one and the 2 distal spines which are longer than the rest with 1 or 2 basal denticles. The 2 distal pecten spines are more widely spaced than the rest. The subventral tuft is minute and composed of 4 simple branches which are shorter than the diameter of the siphon, and the tuft is placed distally to the end of the pecten. Anal segment rather badly damaged. Upper caudal seta missing. Lower caudal seta single. Ventral brush with 4 pairs of tufts in barred area and with several small unpaired tufts proximal to the barred area. Lateral seta and gills missing.

This species is similar to *Aëdes (Aëdimorphus) irritans,* Theo., *hopkinsi,* Edw., *tarsalis,* Theo., and *filicis,* Ingr. & De M., but differs from these having fewer comb scales. *A. yanga~~y~~biensis* differs from *irritans* in having the distal spines of the pecten more widely spaced, and from the other three species in having head seta "B" longer than "C" and the subventral tuft placed distal to the end of the pecten.

m /

Pupa. Two pupal pelts from Yangambi, Belgian Congo *(Parent)*.

The trumpet is similar to that of *hopkinsi,* Edw., *domesticus,* Theo., *filicis,* Ingr. & De M., and *tarsalis,* Theo. The pupa differs from the first three species by the presence of small denticles at the edge of the paddles (internal and external borders) and from the last mentioned species by the general paleness of the paddles which, in *tarsalis,* are infuscated.

Tegument usually pale. The wing sheaths and the trumpets are brownish and the paddles completely pale. Trumpets cylindrical and reticulated with a terminal aperture. Trumpet much shorter than *filicis.* Ratio of meatus: trumpet=1:1.3. Ratio of length of trumpet at widest part=3:1 (fig. 5b).

Dorsal hair slender with a main branch which is divided into 2 at about half way. This hair, together with the other cephalothoracic hairs, is not easily seen. "O" has 6 short branches; "P" single, long, much longer than "R" which has 6 branches; "H" single, simple and short; "K" single, simple and about 4 times the length of "H"; "L" single with apex branched; "M" a small tuft with secondary branches; "S" long and slender with 2-3 apical branches; "T" like "S" but much shorter.

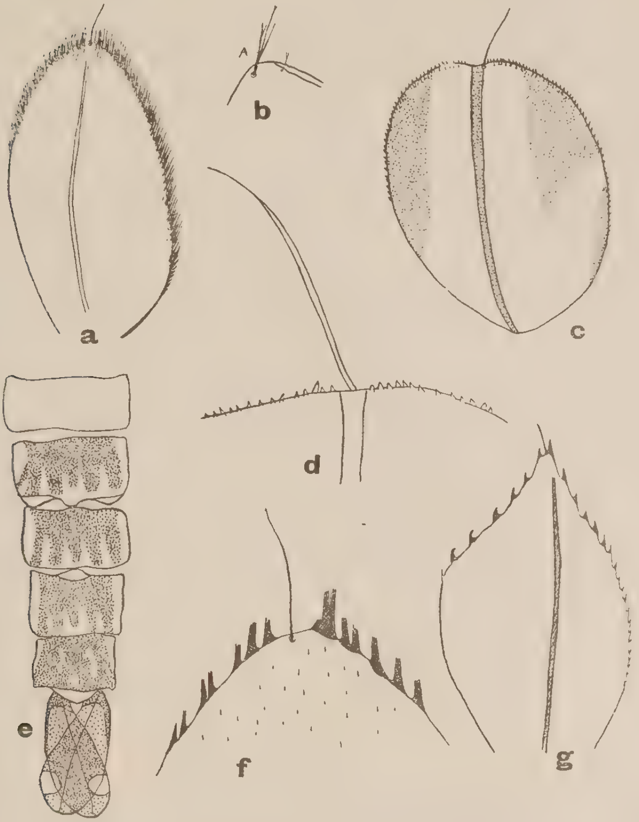

FIG. 4.—*Aëdes* (*S.*) *amaltheus*, De M. : *a*, paddle of the pupa ; *b*, seta VIA of the pupa.—*Aëdes* (*S.*) *calceatus*, Edw. : *c*, paddle of the pupa.—*Aëdes* (*A.*) *marshalli*, Theo. : *d*, apex of the paddle of the pupa.—*Ficalbia* (*M.*) *parenti*, De M. : *e*, segments V–VIII of the abdomen of the pupa ; *f*, apex of the paddle of the pupa.—*Uranotaenia montana*, Ingr. & De M. : *g*, paddle of the pupa.

Float hair normally developed. The abdominal hairs are all short and inconspicuous. "B" III single; "B" IV 3-branched; "B" V and VI 2-branched; "C" II a very small tuft; "A" VIII with 2-3 simple, slender, short branches; "A′" VIII 3-branched, longer but more slender than "A" VIII. Paddles rounded apically. Ratio of length: width at widest part=1.4:1. Small denticles present extending along the internal and external borders of the paddle. Hair of the paddle single, simple, straight, and 1/9 the length of the paddle (fig. 5c).

Aëdes (Aëdimorphus) haworthi, Edwards.

Pupa. Three pupal pelts, one of which is from Livingstone, N. Rhodesia *(Muspratt)*.

The trumpet is similar to that of *A. (A.) wigglesworthi*, Edw. *A. haworthi* is characterised by the length of the hairs in general and more especially by (i) the cephalothoracic and postero-thoracic hairs; (ii) "S" on segment I which is remarkably long; and (iii) "A," " B" and "C" on the abdominal segments ("A" single and long, "B" and "C" tufted and well developed).

The trumpets are reticulated and dark. Ratio of meatus: trumpet=1:1.5. The pupa is brownish in colour, but is darker between the trumpets and on the metathorax and on the first 4 abdominal segments in the central area. The paddles are pale. Dorsal hair consists of 6 pectinate branches which are longer than the trumpets. Supra alar hair has 2-3 branches which are as long as the trumpets. The cephalothoracic hairs are long. "O" is 5-branched, pectinate, with some of the branches bifid or trifid apically; "P" is single; "R" has one main branch which is divided apically into 3 or 4 long and plumose branches; "H" is short and single; "K" single, very long and pectinate; "L" single, simple; "M" is a short tuft but well developed in width and strongly branched; "S" is a stout and exceedingly long, pectinate hair; "T" is 3-branched, pectinate and long, but shorter than "S."

Float hair finely branched and of average development. On segments II and III hair "A" is single and pectinate; hair "A" IV is divided into 2 pectinate branches half way. "A" V and VI are long but not as long as "A" IV. "B" and "C" on segment III are pectinate, much branched and about as long as the succeeding segment. "B" and "C" on segments IV and V are branched and longer than the succeeding segments. These setae attain their greatest lengths on segments IV and V. "A" VIII has 3-4 sub-plumose branches which are as long as the paddles (sometimes one or two branches are shorter than the others). The paddles are short, rounded, and nearly as long as wide. The borders of the paddles are slightly spiculated. Apical hair long.

Aëdes (Aëdimorphus) marshalli, Theobald (fig. 4, d).

Pupa. Fifteen pelts from Potgietersrust, Transvaal *(De Meillon)*.

This pupa possesses the following distinguishing characteristics:

(1) Dorsal hair and cephalothoracic hairs long; (ii) Hair "B" on segments III-VI single and long; (iii) the dorsal surface of the cephalothorax and the first 4 abdominal segments infuscated.

The trumpets of the *hirsutus* group are reticulated and brownish. Ratio of meatus: trumpet=1:1.4. Dorsal hair with 3-4 pectinate branches about equal in length to the trumpets. The 2 postero-thoracic hairs are much longer than the rest, single, stout and pectinate. "O" has 4-5 branches; "P" single and twice as long as "O"; "R" branched and more or less equal in length to "O." Abdominal hairs long and clearly visible. "H" single, short; "K" single, long and pectinate; "L" with 1-2 branches, small; "M" short, tufted; "S" single, long; "T" single, half length of "S" and pectinate.

Float hair dendritic and well developed. "B" III-VI single, pectinate, longer than the succeeding segments. "C" II with 8-10 branches, half the length of the segment; "C" IV-VI with 2-3 branches. "A" II-VI single, long; "A" VII single, pectinate, sometimes forked, more or less half the length of the segment; "A" VIII with 2-4 branches of varying lengths, long and distinctly plumose, stout. The longest branch is more than half the length of the paddle; "A' " VIII slender, bifid.

Paddle much longer than wide (1.6:1). Hair of the paddle single, long, 1/3 the length of the paddle. Apex of paddle slightly denticulate. Midrib pigmented, the rest of the paddle pale (fig. 4d).

Aëdes (Aëdimorphus) durbanensis, Theobald (fig. 5, d, e)

Pupa. Two pelts from Vila de Jaoa Belo, Mozambique, Portuguese E. Africa *(Dr. Rebello).*

This pupa resembles *A. (A.) hirsutus,* Theo., as regards the trumpet, but can be separated from it by the absence of long abdominal hairs.

Colour pale except at the level of the wing sheaths and the trumpets which are light brown (fig. 5d). Ratio of meatus: trumpet=1:1.5. Dorsal hair short and slender with the apex bifid. Cephalothoracic hairs inconspicuous. "O" 5-branched; "P" single, longer than "O"; "R" short and single, placed some distance from "P"; "H" single; "K" single, much longer than "H"; "S" and "T" single and small.

Float hair of average size, dendritic. "C" II a small tuft. The majority of hairs on the abdominal segments II-VII are single (sometimes double) short and inconspicuous. Hairs "B" and "C" are never more than about ½ the length of the succeeding segment. "A" VIII with 3-4 branches, short and simple or very sparsely pectinate; "A' " VIII single, and longer than "A" VIII. Paddles pale, long and narrow, faintly denticulate apically on outer margin. Terminal hair short, straight. Paddles nearly twice as long as broad (fig. 5e).

Aëdes (Aëdimorphus) argenteopunctatus, Theobald (fig. 5, f).

Pupa. One pelt from Livingstone, N. Rhodesia *(Muspratt).*

Pale brown in colour except for trumpets and portions of the wing cases which are dark brown, and area between trumpets and the basal median area of the abdominal segments which are infuscated.

Trumpets of the *hirsutus* group are brownish and reticulated. Ratio of meatus: trumpet=1:1.6. Dorsal hair small with a main branch sub-divided into 8 or 9 smaller branches. Cephalothoracic hairs not unusually long. "O" with numerous delicate branches; "P" long, simple; "H" short, single; "K" much longer than "H"; "S" long, bifid, longer than "K"; "T" with 2-3 branches, shorter than "S."

Float hair dendritic and well developed. Abdominal hairs in general poorly developed. "C" II a very small, multi-branched tuft; "C" III-VI short and with many branches; "B" IV-VI 2-branched, slightly more than half the length of the segment; "A" II-VI short and inconspicuous; "A" VII with 3-4 small branches; "A" VIII with 5-8 short sub-plumose branches; "A' " VIII with one branch, sub-divided into 2 or 3 branches at the apex, slightly longer than "A" VIII.

Paddles very pale with slight infuscation at the apex of the midrib. Apex of paddles with minute spicules. Hair of paddle short (fig. 5f).

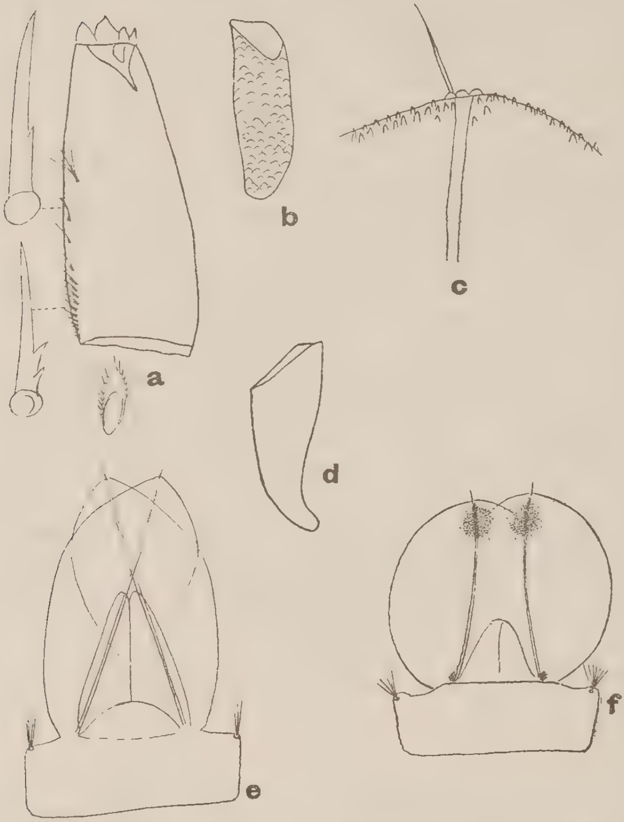

Fig. 5.—*Aëdes* (*A.*) *yangambiensis*, De M.: *a*, siphon, comb scale and pecten spines of the larva; *b*, trumpet of the pupa; *c*, apex of the paddle of the pupa.—*Aëdes* (*A.*) *durbanensis*, Theo.: *d*, trumpet of the pupa; *e*, paddles of the pupa.—*Aëdes* (*A.*) *argenteopunctatus*, Theo.: *f*, paddles of the pupa.

Aëdes (Stegomyia) amaltheus, De Meillon & Lavoipierre (fig. 4, a, b).

Pupa. Five pelts from Livingstone, N. Rhodesia *(Muspratt)*.

This species is near *unilineatus*, Theo., *africanus*, Theo., *luteocephalus*, Newst., and *albopictus*, Skuse, as regards the hairy paddle but differs from the above species in the development of hair "A" VI.

Brownish in colour. Trumpets and area between them and first few abdominal segments slightly darker. Midrib dark brown and the rest of the paddle pale. Dorsal hair with 1-2 branches slightly less than 1/3 the length of the trumpets. "O" and "R" almost equal in length and each with 2-3 branches; "P" single and longer than "O"; "H" single, short; "K" single, very much longer than "H"; "S" single, shorter than "K"; "T" single, shorter than "S"; "B" II-V single, at least $\frac{1}{2}$ the length of the segment; "C" II with 2-4 branches, more or less $\frac{1}{2}$ the length of the segment; "C" III with 1-4 branches; "C" IV-VII with 1-3 branches. The length of hair "C" diminishes from segment III and is always less than $\frac{1}{2}$ the length of the segment. "A" II-V stout, single; "A" VI with 1-2 branches, less than ½ the length of the segment and sometimes forked (fig. 4b). "A" VII with 1-3 branches, long and sub-plumose. "A" VIII with 3-4 branches, sparsely plumose and half the length of the paddle; "A′" VIII single. Paddle of uniform colour. Midrib darkened. Paddle hairs less than 1/3 the length of the paddle. Paddle prominently fringed internally and externally with long delicate hairs and some short colourless denticles (fig. 4a).

Aëdes (Stegomyia) calceatus, Edwards (fig. 4, c).

Pupa. Three pupal pelts examined from Livingstone, N. Rhodesia *(Muspratt)*.

Pupa brown. Trumpets, area between them and first few abdominal segments somewhat darker. Midrib dark brown. Paddles light brown and in extreme cases infuscated as in figure (fig. 4c).

Dorsal hair single and half the length of the trumpets. Hairs "O," "P" and "R" and the hairs on the first abdominal segment as in *A. (S.) dendrophilus,* Edw. "B" II-VI single, simple and black, ½ the length of the segment. "C" II with 3-5 black branches; "C" III-V with 2-3 branches; "A" II-VI small, short spines; "A" VII with 1-2 black, simple branches; "A" VIII with 4-5 minutely pectinate branches (sometimes of unequal length), and 1/3 the length of the paddle. Paddles strongly spiculated on internal and external borders, especially at the apex. Paddles rounded, slightly longer than wide. Terminal hair single, 1/5 the length of the paddle.

This species differs clearly from *dendrophilus,* Edw., in the shape of the paddle and in "A" VIII which is minutely pectinate and not sub-plumose.

Aëdes (Finlaya) fulgens, Edwards.

Pupa. Five pelts from Livingstone, N. Rhodesia *(Muspratt)* and four from Potgietersrust, Transvaal *(De Meillon)*.

This species resembles *longipalpis,* Grünberg, and differs from the other described species of the subgenus in having "C" much-branched on segments III and IV. It differs from *longipalpis* in "C" being nearly as long as or longer than the succeeding segment.

Ficalbia (Mimomyia) parenti, De Meillon & Lavoipierre (fig. 4, e, f).

Pupa. This description is based on the examination of several pupal pelts from Yangambi, Belgian Congo *(Parent)*. The pupa which at first glance resembles *Ficalbia (M.) mimomyiaformis,* Theo., or *F. (M.) hispida,* Theo., can easily be distinguished by the saw-like spines on the distal edge of the paddle on either side of the midrib; by hair "A" VIII which is branched; by the general colour of the body; and by the opening of the trumpet which is larger and more lateral than in the other two species.

Pupa dark brown in colour (more marked than in *F. (M.) mimomyiaformis)*. The abdomen appears spotted owing to the presence of isolated yellow spots in all the segments (fig. 4e). Paddles dark brown with a slightly lighter and diffuse pale area in a semicircle on the external border, at the distal edge. (There is a certain amount of variation in the distinctness of this area.)

Trumpets long and narrow, slightly curved in the distal third. Ratio of length: width of trumpet=18:1.

Tracheoid area slightly distal to the pinna which is on the posterior edge. The extreme distal part of the trumpet is reticulated. Ratio of meatus: trumpet=1:4 (approximately).

Cephalothoracic hairs: dorsal hair 5-branched; alar, ocular and thoracic hairs moderately well developed. "O" and "P" small tufts, equal in size; "R" bifid.

Float hair weak. "H" and "K" long and simple; "H" longer than "K"; "L" 2-branched or single, short and twice as long as "M" which is 4-branched. "L" and "M" are close to each other; "S" bifid apically; "T" 2-branched or single; "S" and "T" are situated close to each other, the one almost directly behind the other; "U" single, small. "A" II-VII single and not well developed; "B" and "C" branched, well developed and more or less the same on each segment (3-4 simple branches). The other hairs are only poorly developed. "A" VIII small, delicate, with 3-5 branches; "A' " VIII single, or apex bifid and nearly as long as "A" VIII. Paddles typical of the subgenus, main hair single. No secondary hair. Spines near the apex of the paddle strong and black with the apices saw-like (fig. 4f).

Aëdomyia furfurea, Enderlein.

Pupa. Three pelts from Livingstone, N. Rhodesia *(Muspratt)*.

This pupa differs very clearly from *A. africana,* N.-L., and all other known Ethiopian Culicine pupae in having hair "A" on all segments modified into a spine and situated in the corner of the segment, a position characteristic of the Anophelines.

The following main characteristics distinguish this species from *A. africana.*

Hair "A" is a spine and situated in the corner of the segments. This hair increases in length and is more and more spinelike from segment II-VIII. Also one of the submarginal setae is modified into a strong, pale spine which decreases in length from segment II-VIII. It would appear that it is not always the same seta that is modified. The hair of the paddle is single and long (longer than the paddle).

Edwards (1941) points out (Mosquitoes Ethiop. Reg., Part 3, p. 372) that the unusual character of seta "A" being modified into a spine was used by Baisas to distinguish *Aëdomyia venustipes,* Skuse.

A. furfurea differs from *venustipes* in having hair "A" modified into a spine on all segments, whereas in *venustipes* it is only on segments II-VI that this modification is found and the spines are only slightly developed.

Uranotaenia montana, Ingram & De Meillon (fig. 4, g).

Pupa. Two specimens examined from Johannesburg *(De Meillon)*.

This species resembles *U. candidipes,* Edw., in the general aspect of the trumpets but is easily distinguished by certain characters.

The trumpets are long and very slightly calciform at the apex and spiculate at the base. Ten times as long as wide. The antero-thoracic hairs are clearly tufted and long (just a little shorter than the trumpets). One of these hairs is very long and single (twice the length of the trumpet).

Abdominal hair "B" as in *U. candidipes,* but with the following differences: The double branches are equal in length and "B" VI is single or double. The paddles are strongly pointed. The spines on the borders of the paddles are much stronger than in *candidipes* and those on the internal border are hooked (fig. 4g).

Hodgesia cyptopus, Theobald.

Larva. Ten pelts from Yangambi, Belgian Congo *(Parent)*.

Head.—Antenna shorter than head and of almost uniform thickness; spiculate and slightly infuscated at base and apex. Tuft situated at 11/12 and composed of about 26 sparsely plumose branches. Head seta "A" with 6 simple branches; "B" single, minutely pectinate and nearly or as long as head; "C" with 3-4 simple branches and "d" with 3 simple branches. Mentum with 1 central tooth and 4 teeth on each side of the central tooth, almost rectangular in shape.

Abdomen.—Comb a row of 9 teeth which are delicately fringed, the fringe enveloping the whole tooth except at the base. The teeth are somewhat variable in size. Siphonal index 1.5. Pecten of 4-5 stout, simple spines extending to just beyond 1/3. Sub-ventral tuft near the base of siphon and consisting of 5-6 simple branches which are nearly 1½ times the diameter of the siphon at the point of attachment. The cuticle of the siphon and anal segment is reticulate. Upper caudal seta with 6 flattened, simple branches and the lower caudal seta with 5 similar branches. The lateral seta is very short, black and barbed and is ½ the length of the saddle. Ventral brush of about 3 pairs of tufts. Ventral margin of anal segment with 5 single or bifid tufts.

Pupa (fig. 2g, h). Ten pupal pelts from Yangambi, Belgian Congo *(Parent)*.

This pupa has the following characteristics:

Light brown in colour. Trumpets, wing cases and lateral apical angles of abdominal segments somewhat infuscated. Paddles slightly darkened at apices. The colour of the pupa, however, is subject to some variation but even in extreme cases it is more uniform than in the other known species of *Hodgesia*.

Hairs "I" and "II" long and simple The trumpets consist of 2 leaflets as in the subgenus. The narrower leaflet which appears to differ in shape from that of *H. nigeriae,* Edw., has a small indentation at the apex (fig. 2h). Dorsal hair with 1-4 branches which are simple. The other hairs are small and inconspicuous. "O" 3-4 branched; "P" with basal half strap-like and apical half finely divided and resembling a " cat-o'-nine-tails." These 2 hairs are placed close together. "R" single, long and slender, 2 or 3 times as long as "P."

Abdomen.—Segment I, hair "H" single; "K" with 3-4 branches with a long stem, twice as long as "H"; "L" and "M" short, branched; "S" single, longer than "K"; "T" single, shorter than "S"; "U" single and minute.

Segments III-VII hair "I" single or double; "A" single or double; "B" single and at most half the length of the segment.

Segment VIII, hair "A" single; "A′ " bifid and longer than "A." Paddle with terminal indentation. Apex of paddle denticulate and infuscated. Hair single (fig. 2g).

PHYSIOLOGICAL AND ECOLOGICAL STUDIES OF THE SPECIES OF *CAPNODIS* IN PALESTINE (COL., BUPRESTIDAE).

II.—STUDIES ON THE LARVAE.

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Breeding Methods.

There are many difficulties in breeding an insect such as *Capnodis,* which lives in the roots of certain trees; the larva, for instance, is hidden throughout its entire development, and it is impossible to carry out certain aspects of the experimental work on larvae in the roots of even a small tree. Branches of almond 15-25 cm. long and 2-5 cm. in diameter were therefore utilised for the purpose.

The neonate larva was placed in a small slit in the bark of the wood into which it penetrated. The larva could be removed from the wood at any desired interval and placed in a fresh piece of wood. Ordinarily one larva required about three or four pieces of wood in order to complete its development. When a larva became full grown, it was more difficult to place, and it was therefore necessary to make a larger slit, tearing the bark from the wood close to its edge, before inserting it. The larva needs firm support for its thorax and abdomen before it can gnaw its way into the wood—the larger the opening, the easier it gnaws into it. After the larva had established itself in a new piece of wood, it could be subjected to any desired temperature or humidity; experiments in toxicology could also be carried out more advantageously.

This method was by no means always successful, and it may be of interest to indicate some of the reasons for this, because it throws light on what happens in the grove, which is of great concern to the fruit grower.

The pieces of wood, which serve as food, may dry up to such an extent that the larva finds difficulty in feeding on it. It is essential to keep the wood fresh by placing one end in water. On the other hand, excessive moisture is detrimental, and larvae were very often found dead in that part of the wood which was close to the water. In order to avoid this, the pieces of wood were placed in a minimum amount of water or in moist sand, and the position changed from time to time, each end resting on the sand alternatively.

It often happened that larvae, especially when very young, were drowned in the gum which oozed from the branch. To overcome this, older branches were chosen for food and allowed to wilt three or four days prior to placing them in water or sand. The influence of such factors in the orchard will be discussed later.

Description of Larva.

Like other Buprestid larvae, those of *Capnodis* are creamy white, with a small head, a greatly expanded prothorax, and a slender body composed of the remaining two thoracic and ten abdominal segments. The legs are absent; two papillae near the metasternum represent the atrophied posterior legs.

Some of the organs of the head are well developed; labrum and mandibles are distinct; maxillary and labial palpi are considerably reduced. In addition, the antennae in the mature larva are represented by two segments bearing two fine, minute bristles (see fig. 1). The posterior part of the head is membranous and merges with that of the neck and is capable of being withdrawn within the prothorax. The neck and prothorax may be distended in all directions. When distended, they may be held in this position by air which is inhaled in the over-developed prothoracic trachea. This character proves useful when burrowing in the ground, or in the root, between the bark and the stem.

The tergum and sternum of the prothorax are thick, and stronger than those of the other segments. The tergum bears a chitinised thickening in the form of an inverted V, while the sternum bears that of an inverted T. These chitinised areas with their strange muscular attachments render the prothorax strong and well adapted for burrowing.

The mesothorax is the narrowest of the body segments. The thoracic spiracles are situated near the anterior margins of its pleura. The third, fourth and fifth abdominal segments are the largest. As in other Buprestid larvae, the segments are rectangular, arranged in a chain-like, not telescopic, fashion, and are wrinkled laterally. On the side of each of the body segments in young larvae, there is a tuft of fine, clavate hairs. The tufts are inconspicuous on the anterior segments of the body but become stronger posteriorly so that the ninth abdominal segment has over two dozen such hairs on each side. The hairs are conspicuous and stronger in the larva of *Capnodis miliaris* than in the larvae of the other three species under observation—*C. carbonaria, C. cariosa* and *C. tenebrionis*. As the larva becomes mature, these tufts of hair disappear as is discussed below. In the younger larvae, they serve for locomotion in burrowing in the ground; as soon as the larva has reached the wood, the hair tufts are no longer needed.

Locomotion of Larva.

Free neonate larvae crawl easily on all horizontal objects, but over a smooth surface, such as glass, they find it rather difficult. The larva does not crawl on its ventral side, but by means of its lateral tufts of hair. The body movements during locomotion are very similar to that of a crawling caterpillar, the thorax anchors itself to the object, and the rest of the body contracts. With the aid of the anal hair tufts, the last abdominal segment in turn anchors itself, and the abdominal segments extend, first the posterior, then the others. The extended abdominal segments form an arch, which moves from the posterior end in a wave-like fashion anteriorly to the thorax, which in turn moves forward and so on. Immediately after hatching, the larva tends to burrow and penetrates into the ground by wriggling movements of the entire body. With the aid of the hair tufts on either side of the body, the larva is able to anchor itself between the earth particles and penetrate deeper. The particles of earth must therefore be slightly firm in order to enable the larva to advance. For this reason larvae cannot penetrate through dry sand, since small particles of sand offer no grip for the head and thorax, which are the first to penetrate the surface. Several tests were made, but in no case did a larva succeed in penetrating dry sand. Upon a surface of wet sand, it was always easier for the larva to penetrate, especially through a furrow or near a minute pebble.

The depth to which the larvae can crawl depends, also, upon the type of soil, as will be seen from the following series of experiments. Three tubes, 50 cm. long, were filled with dry sand, dry red sandy soil, and dry clay soil. A small piece of almond twig was placed at the bottom of the tube and 50 larvae of *C. carbonaria* were set free on the surface of the soil in each tube. After four days the pieces of twig were examined for larvae, and those embedded in the sand or the red, sandy soil, were found to be entirely free, but 41 of the larvae were found in the twigs which were inserted in the heavy soil. The experiment was repeated, with approximately the same results.

Pieces of twig were placed in vessels 20 cm. high, covered by a column of heavy, dry earth, the upper layer consisting of a moist, pounded layer of the same soil. From 10-35 per cent. of the larvae were recovered in the twig, in most cases regardless of whether the pounded layer was one or four cm. thick. When the pounded, moist layer was increased to ten cm., none of the larvae succeeded in getting through. The depth to which the larvae can penetrate depends, therefore, upon the type of soil, its moisture, and on the amount of free spaces between the soil particles.

Tests were carried out to determine how far larvae will crawl over a surface in search of food. Dry earth was strewn over a rectangular area of 50 by 130 cm. on the floor of a room, and 100 larvae of *C. carbonaria* placed in it. Pieces of twig were then placed at distances of 40 cm. and 65 cm. from the edges of this earth covered area. When the twigs were examined 3 days later, about 10 per cent. of the larvae were recovered in those that were at a distance of 40 cm., but none in the more remotely situated ones. The experiment was twice repeated, with approximately the same results.

As soon as the root is reached, the larva looks for some crevice or split in the bark through which to penetrate; this is absolutely necessary in order to offer a grip for the head and thorax in gnawing its way through.

As soon as it penetrates into the roots, the larva advances in the gallery by means of the muscular movements of the body. The abdomen leans against the walls, and the entire body is stretched and pushed forward. In the course of the laboratory breedings, when large larvae were to be transferred into fresh pieces of wood, it was found absolutely essential to make a large split between the bark and the wood in order to offer a foothold, at least for the thorax and the first abdominal segments. When an additional point of support was offered for the rest of the abdomen, the penetration was greatly facilitated. At all times, while burrowing in the wood, the respiratory movements of the prothorax are of great assistance.

Reaction to External Stimuli.

(a) *Stereotactic Reactions.*

The tendency of the neonate larva to burrow into the ground until it finally finds the roots of the tree has already been mentioned. This tendency is governed primarily by positive stereotactic reactions.

(b) *Phototropic Reactions.*

Negative reactions to light have nothing to do with the tendency to burrow. This was proved by an experiment in which 100 larvae in a petri dish collected and crowded themselves under a transparent glass plate which touched the dish on one side, and not under an opaque plate which was slightly elevated above the bottom of the dish. The larvae preferred contact with the solid transparent glass on either side, to the more spacious, darkened area.

(c) *Geotropic Reactions.*

A piece of almond twig was inserted at the opening of one arm of a U-shaped tube, filled with earth. At the opening of the other arm, 50 neonate larvae of *Capnodis tenebrionis* were placed. Several of these crawled down one arm and up the other to penetrate the twig. This shows that the larva is not guided to its food by geotropic reactions.

(d) *Chemotropic Reactions.*

It was demonstrated by a series of experiments that the odour of the root serves as the chief guide in enabling the larva to locate it. In the experiment mentioned above, pieces of twig were placed on the floor of the room, covered with a 2 cm. layer of earth, and located by the larvae at a distance of 40 cm. Pieces of almond wood were placed at the bottom of a flower pot 40 cm. high, which was filled with earth. A large percentage of the larvae, which were liberated on the surface of the pot, located the pieces of wood. Three glass tubes, 75, 100, and 125 cm. long, respectively, filled with earth, were placed in a vertical position. A piece of almond wood was placed at the bottom of each tube, and on the top of the soil 100 neonate larvae of *C. tenebrionis* were set free. On the fourth day the pieces of wood were examined, as well as the earth in its immediate vicinity. In the first tube, 44 larvae were recovered, in the second 32, and in the third only 7.

In another series of experiments carried out with a variety of plants, pieces of twig, 6-8 cm. long, were placed at the periphery of a large glass dish 30 cm. in diameter and about 6 cm. high, and covered with slightly moist earth. One hundred larvae of *C. tenebrionis* were set free in the centre and thinly covered with earth. At the end of the third or fourth day the twigs were removed and the larvae therein counted.

In the first experiment twigs of almond, cypress, *Ficus nitida* and mulberry were used, in the second those of almond, apple root stock, sweet apple and pear, and in the third those of almond, apricot, peach and plum. In each test two twigs of plant were used, and each experiment was repeated three times. The results are given in Table I, in which the following are the outstanding features:

(a) In all three experiments only about 33 per cent. of the larvae were recovered. The others died in the ground or wandered about in the dish and finally died. Fewer larvae were recovered in very moist soil, a greater percentage having died.

(b) In all cases almond attracted the largest number.

(c) The more closely related the plants were to almond, the more larvae they attracted.

TABLE I.

Kind of twig	No. of larvae recovered in trial			Total recovered	Percentage recovered
	A	B	C		
Almond—*Prunus amygdali*	25	41	17	83	32
Cypress—*Cupressus* sp.	4	5	1	10	
Ficus nitida	1	2	0	3	
Mulberry—*Morus alba*	0	0	0	0	
Almond—*Prunus amygdali*	10	23	15	48	33
Root stock apple—*Pyrus* sp.	3	12	5	20	
Apple—*Pyrus malus*	6	9	5	20	
Pear—*Pyrus communis*	1	4	5	10	
Almond—*Prunus amygdali*	11	13	10	34	33
Apricot—*Prunus armeniaca*	8	9	12	29	
Peach—*Prunus persicae*	5	8	13	26	
Plum—*Prunus salicina*	3	3	4	10	

In a petri dish 15 cm. in diameter, two almond twigs and two *Pistacia lentiscus* twigs were placed at the bottom along the periphery and covered with earth, and in the centre 25 larvae of *C. carbonaria* were released. In another dish 25 larvae of *C. tenebrionis* were placed, and in a third 25 larvae of *C. cariosa*. Three days later, in the first case, no *C. carbonaria* were attracted to *Pistacia,* but ten were found in the almond twig. Similarly, no *C. tenebrionis* were attracted to *Pistacia,* but 13 were found in the almond twig. In the case of *C. cariosa,* however, four larvae were found in *Pistacia,* and two were found in the almond. When this latter experiment was repeated, 16 larvae were recovered in *Pistacia* and two in almond.

In another experiment five twigs were placed in a larger dish, 30 cm. in diameter. The following were used: rose, Pitanga cherry *(Eugenia uniflora)*, apple, plum and almond. Fifty larvae were placed in the centre of each dish. This experiment was carried out 12 times, six times with larvae of *C. carbonaria* and six times with larvae of *C. tenebrionis*. Three days later the twigs were examined and the total number of larvae recovered from each host-plant in the six experiments are given in the following table:—

TABLE II.

	Rose	Pitanga	Apple	Plum	Almond	Total recovered
C. carbonaria	0	7	30	56	86	181
C. tenebrionis	1	2	31	61	89	184

The root odour was also tested in this manner. One piece of almond root and one piece of apricot root were placed at the edge of a petri dish, and 50 neonate larvae of *Capnodis* were liberated in such a way that the distance between the larvae and the pieces of root was equal. The pieces of root were examined three days later. The same experiment was carried out ten times, five times with *C. carbonaria* and five times with *C. tenebrionis*. Counts showed that 38 larvae of *C. carbonaria* were recovered in the root of almond and 42 in apricot, while 73 larvae of *C. tenebrionis* were recovered in almond, and 52 in apricot.

The value of chemotropic reactions in neonate larvae are clear. They enable the insect to locate its natural food, but as soon as the larva has found a root and burrowed into it, the remainder of its larval and pupal life is spent there and it does not leave until it becomes an adult. With larvae of later instars, therefore, chemotropic responses are superfluous.

Three experiments were carried out to determine whether larvae one week or more old, having been removed from the wood, still retain the ability to detect food from a distance by means of chemotropic reactions.

A cylinder of an almond branch, 2.5 cm. in diameter, and 3 cm. high, was placed in the centre of a glass dish 30 cm. in diameter. Moist earth was strewn over the dish and five groups of larvae were set free along the periphery. In the first experiment, there were eight larvae in each group, four neonate larvae and four five-day old larvae, probably in the second instar, having a prothorax about one mm. wide. Two days later, upon examining the wood, five of the neonate larvae were found in the almond cylinder and only one of the older larvae. The second experiment was similar, except that the older larvae were about 10 days old, having a prothorax of 1.5 mm. to 2 mm. wide, namely, larvae of the third and fourth instars. Upon examining the wood, three neonate larvae were recovered in the almond wood, but none of the older larvae. In the third experiment, four larvae were used in each group, two neonate and two 12-day old larvae of the fifth instar, having a prothorax of 2.5 mm. wide. Upon examination, five neonate larvae were recovered in the wood, but none of the older larvae.

Of the fifty neonate larvae used in the three experiments, 13 were recovered in the wood, while of the 50 older larvae, only one of the second instar was found. It should be pointed out that the older larvae did not remain immobile, but crawled about, apparently aimlessly, until their strength was exhausted; they progressed in a zigzag fashion and on several occasions came very close to the piece of wood. It is concluded, therefore, that the sense of odour, which enables the larva to detect its food from a distance, gradually weakens until in a larva 12 days old it no longer exists.

The case is different when a larva is brought into direct contact with food. Unless the larva is in the pre-moulting stage, it immediately begins to burrow into the slit made in the wood and commences to feed.

In connection with the sense of smell, it is of interest to note the changes which take place in the antennae of the larva in its various instars. The olfactory organs are probably located in the antennae, and if the sense of smell disappears in the latter instars, they might be expected to disappear or become vestigial. Microscopic examination of the antennae shows that the antenna of the first instar (fig. 1a) is composed of two well developed segments of about the same length, the second being slightly narrower than the first. The first segment bears a seta at its distal margin, while the second has at its base two pores and a sensory, horn-shaped, membranous process. The apex of the segment is membranous and bears sensory pegs as illustrated in fig. 1a. All these organs are probably of an olfactory nature. The antenna of the mature larva is an entirely different structure. The first segment is large and richly decorated with setae and bristles at the distal margin. The second segment is small and vestigial; it has two very large setae at its lateral margin, with very many bristles, and setae along the chitinous margins. The membranous apex is not distinct. A triangular chitinised tongue, with two processes, as illustrated in fig. 1b, is situated at the base of the segment. There is no sign of pores, membranous process, or sensory pegs. This type of antenna, with numerous setae, suggests that it is an organ in which the sense of touch is located. Larvae of the second and third instars have antennae like those of first instars, while the examination of two larvae of probably the sixth and seventh instar reveals antennae similar to those of a mature larva.

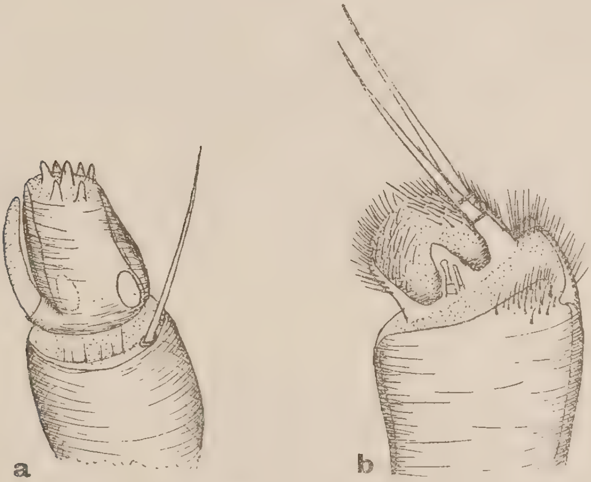

FIG. 1.—Antennae of neonate (*a*) and mature larvae (*b*) of *Capnodis tenebrionis* showing differences in sense organs.

Feeding Habits.

The larva of *Capnodis* feeds by tearing off particles of the inner bark, from which it extracts the juice by chewing and finally discarding the remainder—very much like children eating sugar-cane. The dried discarded remains, called "frass," are thrown sideways, and then by lateral movements of the thorax and abdomen are packed closely behind in the gallery, which is formed as the larva advances. The faeces of the larva are also found in the gallery with the frass. Microscopic examination of the frass shows that it is composed primarily of long fibres and sclerenchymatous tissue with very little of a parenchymatous nature. Microscopic examination of fresh faeces shows some minute particles of wood tissue, which indicates that in addition to the juice, microscopic solid food particles are also ingested. Chemical analysis shows that the frass contains less sugar than the wood from which it was torn off.

As a rule the larvae feed upon the inner portion of the bark and cambium of the roots and trunk, and to a less extent on the wood. In the laboratory, however, it was found that the larvae often made galleries in the hard wood. This took place more particularly when the bark dried, whilst the wood within still remained fresh. In one case, a cut of 5 mm. wide and 8 mm. deep was made in a piece of wood which was extremely dry and hard. In another instance, a larva burrowed into the hard wood to a depth of about 10 mm. The galleries extend along the root until the larva reaches the root crown, where the food facilities enable the larva to complete its development and pupate. In confinement, when food was limited, the larvae turned back to make a new gallery adjacent to, or crossing, the old. When three or four larvae were bred in one piece of wood, it often happened that not all the larvae were recovered; it is therefore very likely that one larva may have devoured another, when it happened to be in its way.

The incision and deep galleries which some *Capnodis* larvae make in hard and dry wood is most astonishing. It is true that they have very powerful mandibles, but it is still difficult to imagine that mechanical activity alone can be responsible. A more critical study was, therefore, made of the method of feeding and digestion of the larva.

Alimentary Secretion.

It was noticed that when a larva is actually feeding, the wood in the gallery at its head is moist, and close observation disclosed that the larva secretes a fluid from the mouth that moistens the wood. A larva may often secrete drops of this fluid even after it has been disturbed and removed from its food.

Drops of this secretion were collected on several occasions and tested. Dissections of larvae indicate that the fluid originates from the fore intestine. As a rule it is brown and translucent; at other times it is turbid, and yellowish in colour. It is sticky, viscous, and dries quickly. The dried substance may be redissolved in water, and the qualities of the original fluid appear to be retained in this solution.

As preliminary tests of its physiological action upon plant tissue, slices of wood were moistened with the fluid. When dried, they were much more brittle than non-treated wood. When a drop of the fluid was placed upon a thin section of grapefruit albedo, it swelled far more readily than a control section, which was placed in water, and after a few days showed signs of disintegration.

(a) *Effect on Tissue.*

A few drops of fluid were diluted in a small amount of distilled water and a few sections of almond bark, as well as hard wood, were immersed in it. As a control, sections of wood were immersed in a small amount of distilled water. Forty-eight hours later, while the control sections remained stiff and firm, those treated in the fluid solution became softened and could with difficulty be spread upon the object glass slide for examination.

Microscopical examination and measurements before and after the treatment disclosed the following features. In the control sections which had been immersed for two days in water, the cell walls swelled very little, and did not appear as if they had absorbed much water. The cell walls were distinct, bright, and had sharp outlines. In some areas, the tissue was torn, but as a whole the entire section was firm. In the treated sections the cell walls had become swollen, their measurement before the treatment ranged from 3-5 microns, while after treatment from 6-8 microns. The cell walls were not uniformly thick, and not distinctly defined; they were turbid and showed signs of disintegration. In a few sections the cells were no longer distinct, but appeared as a formless mass. Fibres had not grown in thickness, but had become separated. As a whole, the section was torn, soft, and showed distinct signs of disintegration.

Further microchemical and physiological tests were made in order to study the effect of the fluid upon the following main constituents of plant tissue: (a) sugar; (b) starch; (c) pectin; (d) lignin; and (e) cellulose.*

(b) *Activity on Sugar.*

An experiment was first made to test for sugar in the bark. Fresh bark was boiled twice in water, and the resulting extract was reduced to a small volume. One drop of the concentrate was tested twice with the Molish reagent on a slide. The reaction was very weak and not instantaneous.

Drops of the stomach juice were put on strips of filter paper and the dried spots tested with Fehlings reagent. Upon drying over an alcohol flame, the reaction for reducing sugars was doubtful, the colour was dark copper-red brown, while the control was negative. From this it is concluded that some sugar inverting enzyme may be present.

(c) *Activity on Starch.*

A drop of diluted fresh fluid was placed upon a small section of almond bark. After 18 hours it was washed and treated with a solution of iodine in potassium iodide. As a control a section of bark without the fluid was similarly treated. Both sections showed equal amounts of starch granules.

On another occasion sections of bark were treated with a drop of the concentrated juice, but the test for starch was negative, both in the control as well as in the treated sections.

Pieces of frass, as well as sections of wood from the inside of the larval gallery, which were soaked in diluted juice for three days, were treated with the iodine solution, and abundant starch was found in both cases. From this it is evident that the secretion of the larva does not affect the starch, which is found in the wood cells, but when a pure solution of soluble starch was tested, the results were different. In a testing block, three drops of iodine potassium iodide solution were placed together with a 0.5 per cent. solution of soluble starch. When the juice was added to this solution, there was a rapid discolouration; a violet intermediary hue could be noticed. The starch solution was entirely discoloured after 15-30 seconds. The reaction was especially striking when small particles of dried up digestive juice were added to the reaction mixture. An amylase which acts upon soluble starch seems, therefore, to be present.

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* The microchemical analyses were carried out by Dr. Paul Haas, while the plant physiological tests were made by Dr. Mina Nadel-Shiffman. The writer wishes to express his sincere thanks and appreciation to them for carrying out this work.

(d) *Activity on Pectin.*

A test for pectin by the Ruthenium red method was carried out in a similar way; no distinct difference could be observed between the treated and non-treated sections, but when soluble pectin was applied, once again different results were obtained.

A solution of 5 per cent. soluble pectin was made. To quantities of 0.1 cc. of this solution, 0.1 cc. of methylene blue was added, and 10 drops of diluted juice. As control, water was applied, either instead of the juice, or instead of the pectin. There was a difference in change of colour between this and the control. In the control, when pectin dye and water were used, the colour changed towards violet, and coarse particles were precipitated; while in the test where pectin, dye and juice were applied together, the colour was Prussian blue and fewer and finer particles were precipitated; after an interval the colour changed to that in which water and dye alone were used. When safranin was applied instead of methylene blue, similar results were obtained. These microchemical tests prove conclusively the presence of a pectinase.

(e) *Activity on Lignin.*

Sections of wood bark, which were tested with a drop of the fluid and other control sections, were treated with a phloroglucinol HCl solution. The test for lignin was strongly positive in both, and scarcely any difference in colouration was noticed in either the treated or non-treated pieces of wood; on the contrary, treated sections showed an even more intensive reaction.

(f) *Activity on Cellulose.*

Sections of wood were immersed for three days in the digestive fluid and then tested for cellulose by the zinc chlor-iodide method. In the control section the cell walls showed a distinct bluish-violet tinge, while in the treated section all cell walls were brownish in colour, indicating the absence of cellulose and a greater abundance of lignin.

a/ A test for cellul~~o~~se was also made with Congo red. Three days after immersion in the digestive fluid, sections were stained with Congo red. The sections which were immersed in the fluid were not stained at all, thus showing the absence of cellulose, while the control sections were distinctly stained with the typical Congo red colour, indicating the presence of cellulose.

In this connection it should be mentioned that a chemical analysis for hemicellulose was made of wood and frass from the same source. The analysis was made from dry matter in both cases. While the wood contained 16.3 per cent. hemicellulose, frass contained 20.9 per cent., indicating an increase of about 4.5 per cent.

The results of the foregoing experiments indicate that the fluid secreted from the mouth of the larva contains a cellulose, and also a pectinase, two agents that render the wood soft and more digestible. In addition, an amylase and perhaps some sugar inverting enzyme may be present.

Development.

(a) *Rate of Development.*

The rate of development of the larva naturally depends upon the quality of the food and upon the temperature. Dry branches or hard wood retard the development; on the other hand, roots of loose tissue such as the roots of apricots or mirobalan accelerate their development.

Since the food in the laboratory was not uniform, and the course of development was interrupted at each transference from one piece of wood to another, the data for the calculation of the temperature-development relationship proved unreliable. Further, these data cannot be relied upon, since the exact time of moulting and of pupation was not known in each instance because daily observations were impossible.

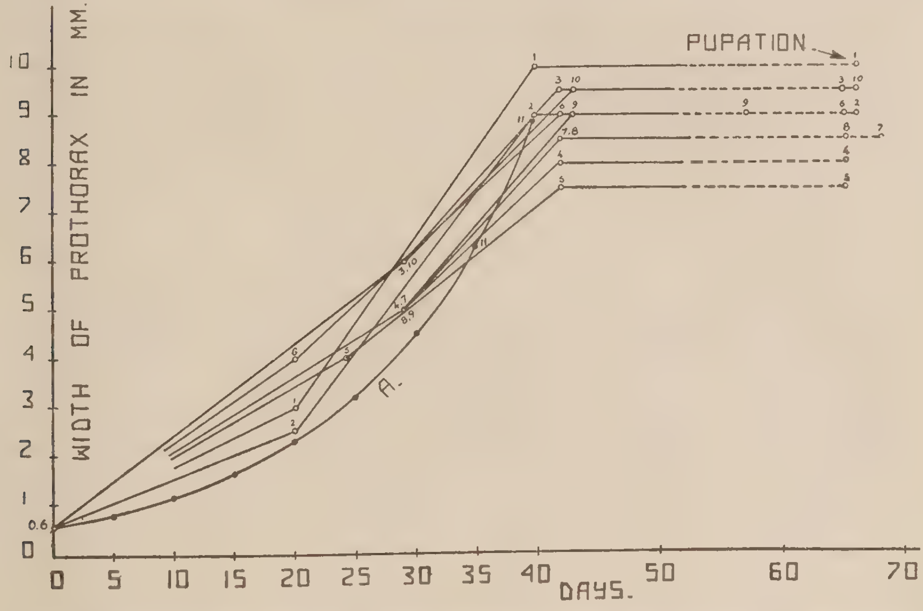

FIG. 2. Rate of growth curves of *Capnodis tenebrionis* at a temperature of 33°C. Lines 1–10—individual measurement records ; line A—calculated data according to Dyar's law.

At the same time it has become evident from a few breedings that the development of the larvae from the time of hatching to pupation at a temperature of 33° C. takes about sixty days (see fig. 2).

The 15 larvae that hatched on 20th July, 1943, emerged as adults during the second week of October, consequently taking 75-85 days. If about 10 days is allowed for the pupal stage, and a few days for the adult to harden in the cell before emergence, the above-mentioned estimate is obtained. This figure is substantiated by individual cases in which the gallery of the larvae was accidentally opened during or very soon after pupation.

As a rule, at a temperature of 27° C., over 100 days were required before a larva showed signs of prepupation. Breedings during the year showed that the development lagged and even came to a standstill as the temperature decreased during the winter months. Only one of ten larvae reached the adult stage after 80 days; the others took longer.

(b) *Threshold of Development.*

If the threshold of development could not be obtained by calculation from data of development at various temperatures, it was at least possible to establish it from direct empiric data.

Breeding of larvae was carried out towards the end of the summer and until late in the winter in a cellar where the temperature was more or less stable, but decreased gradually from 22° C. in November to about 20° C. in December and

18⁰ C. in February. In order to study the rate of development, the rate of growth of the larvae was taken as an indicator. The phase of growth is discussed at greater length below, and it is sufficient to point out here that before the larvae were placed in the pieces of wood on 10th November, the width of the prothorax was measured and recorded in each case. It was again measured when the food was changed on 10th December and again at the end of February. The rate of growth of ten larvae of *C. tenebrionis* from these breedings is presented in fig. 3. The curve below represents the temperature in the cellar during the same period.

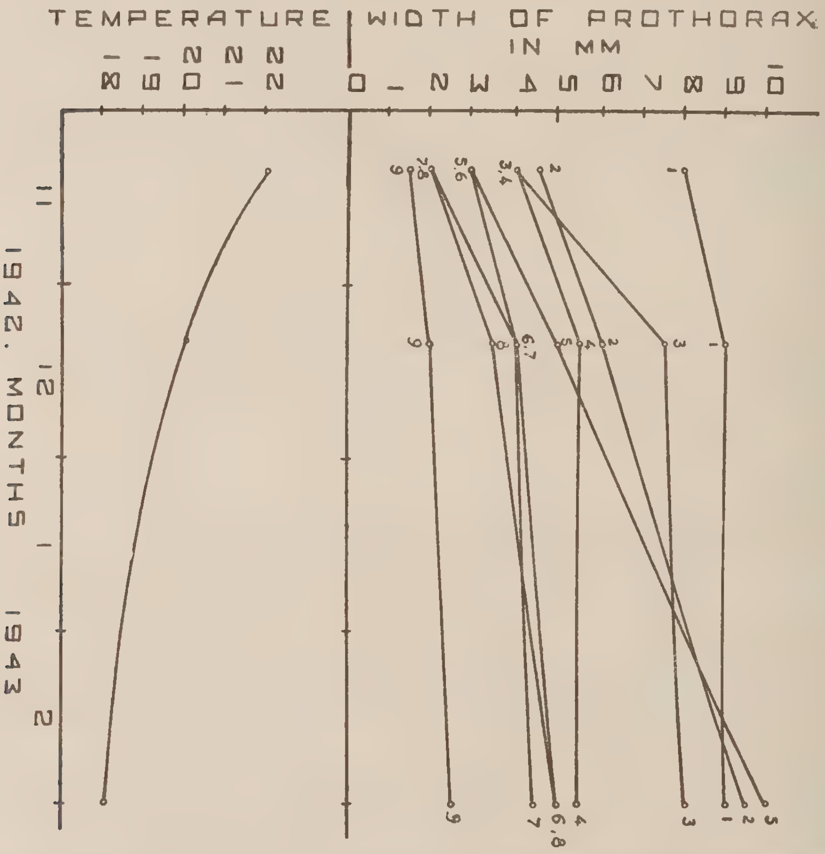

FIG. 3.—Rate of growth curves of *C. tenebrionis* at a temperature decreasing gradually from 22–18°C.

Studying this graph it is apparent that little growth took place when the temperature was above 20⁰ C., but when the temperature fell below 20⁰C., hardly any development took place. Two individuals only developed from medium to full size larvae during this period, the others did not grow more than one or two mm. in width of the prothorax. Under favourable conditions of temperature, a larva might have completed its entire development during this period, which lasted about 11 weeks. At a temperature of 18-20⁰ C., the larvae scarcely developed at all and if the temperature had remained at 18° C. throughout the period, it is unlikely that any development would have taken place. The threshold of development is, therefore, taken to be slightly lower than the calculated figure.

Before moulting, the larva builds an oblong cell by pressing with its body the frass against the walls of the gallery anteriorly and posteriorly. The larva then assumes a curved position fitting into the cell in such a way that the tip of the abdomen touches the thorax. The skin loses its translucency and becomes opaque creamy white and the thorax and head become distended. Within a day or two the thorax splits dorsally; the new head and thorax emerge, and are followed by the entire body, which emerges from the old shrivelled skin.

(c) *Rate of Growth.*

Larvae, which happened to be in process of moulting when the piece of wood was opened, could not be placed immediately into fresh food. These were put in a closed dish until the moult was completed and then transferred to a new twig. This procedure offered an opportunity to study the rate of growth in size from one stage to the next. The old cast off head was measured along the bases of the mandibles, and the new head was similarly measured. It was established that in normally growing individuals the head increases about 1.4 of its previous size; in other words, Dyar's law holds true for *Capnodis* larvae. It was found in the case of underfed, or starving, larvae that there may be a moult with but a very slight increase, or no increase, in size. In a few cases the new head was very little larger than the cast off head.

The prothorax, with its dorsal and ventral chitinised plates, may also be used as a measure of the rate of growth. As mentioned above, when larvae were changed from one piece of wood to another, the width of the prothorax was always recorded. It was then possible to study the rate of growth in normal individuals, and establish the number of moult. The prothorax in the neonate larvae of *C. tenebrionis* is about 0.6 mm.; at the time of pupation it is about 9-11 mm. Applying Dyar's law, we find the larva must moult at least nine times before reaching this stage. If it is borne in mind that at a temperature of 33° C. this entire process takes place within a period of 40 days, as illustrated in figure 2, it is concluded that each instar lasts four-five days. If a curve of Dyar's law as applied to *Capnodis* is now plotted it is not found to bear a close resemblance to the empiric data which are plotted on the same graph (fig. 2). In this figure a circle represents an empiric record, and a dot the calculated data, according to Dyar's law. Line A represents the curve of Dyar's law as calculated for *Capnodis,* whereas the other numbered lines are development curves, based on measurements of individual larvae.

(d) *Length of Life of neonate Larvae.*

The life of this larva, as with other insects, depends upon conditions of temperature and humidity. In cases of extreme drought the larvae are short-lived, surviving for a few hours only, even in a moderate room temperature in the summer. On the other hand, at a humidity of 80-90 per cent., the larvae may live for five or six days at a temperature of 26° C. When the humidity is saturated, or under conditions of excessive moisture, the larvae may be long-lived, but are inactive. They remain immobile, turgid and attached to the surface upon which they happen to crawl until they finally die. Should they be removed and dried before they die, they may begin wriggling or crawling again.

Experiments were carried out to determine the longevity of neonate larvae, without food, at a temperature of 27° C. and 13° C., respectively. The humidity was not controlled, but varied from 65-90 per cent. The mortality in these two cases is presented in fig. 4. It may be noticed that while all of the larvae died after three days at a temperature of 27° C., at a temperature of 13° C. 50 per cent. lived over ten days, while the oldest lived three weeks.

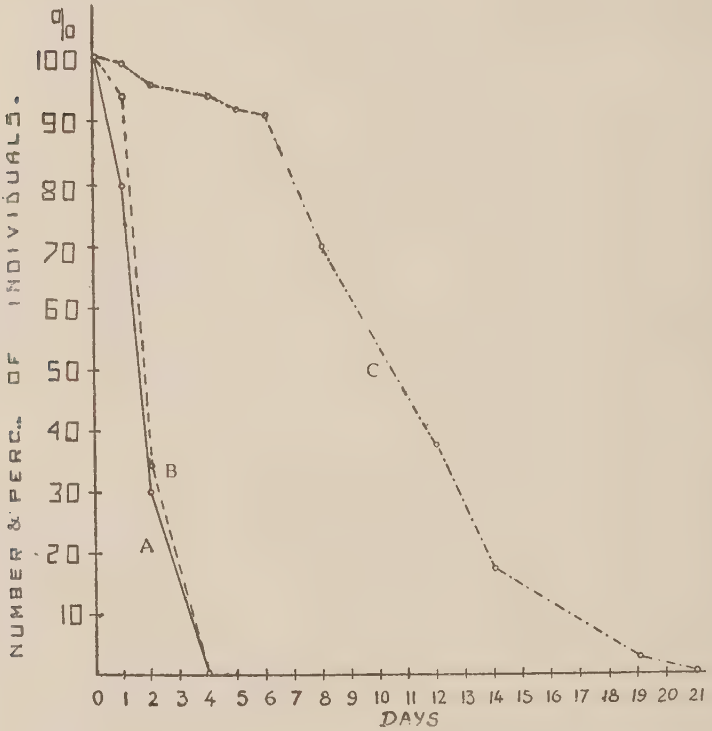

FIG. 4.—Mortality of unfed neonate larvae at temperatures of 27 and 13°C.
Line A at a constant temperature of 27°C.
,, B ,, room temperature averaging 27.5°C.
,, C ,, constant temperature of 13°C.

Resistance to high Temperatures.

A few experiments were carried out to establish the resistance of *Capnodis* larvae to high temperatures.

Pieces of wood, containing larvae about one week old, were placed in a thermostat at a temperature of 46° and 50° C. for various lengths of time. A day or two after their removal from this temperature, the bark of the wood was peeled off and the living and dead larvae counted. In one series of experiments, larvae were exposed to a temperature of 46 and 50° C. for two, four, six and eight hours. In each case several larvae were employed.

At 46⁰ C. about 75 per cent. of the larvae were recovered alive, but there was no marked difference in mortality whether the larvae were in this temperature two or eight hours. At 50⁰ C. about 50 per cent. of the larvae were recovered, but here, too, a similar difference in the time factor had no effect. In another series of experiments in which the larvae were exposed to 46⁰ C. for a few days, total mortality ensued. At 40⁰ C., after 36 hours of exposure, sixteen dead and two living larvae were recovered, while after 48 hours at this temperature, 30 larvae in all were found dead.

Practical Considerations.

(a) *Infestation from infested Root Remains.*

On several occasions the writer has been asked whether a new stone fruit plantation is liable to a heavier infestation if planted on land from which old infested trees have been uprooted, and whether the larvae will leave old infested roots and crawl to those of the new trees. From the experiments on chemotaxis with older larvae, it becomes obvious that mature larvae cannot locate a root even though it may be only a few centimetres away, having lost the faculty of locating food by odour. The answer to the latter question would, therefore, be in the negative. Adult beetles may, however, emerge from an infested field as much as two years after the trees have been uprooted. If quickly developing larvae need at least one summer for their development, poorly fed individuals may take very much longer, and take two years to complete their development. Consequently the answer to the first question would be in the affirmative. From a horticultural point of view, it is not advisable to replace uprooted trees by those of a similar kind, but if a farmer has limited land and must replant the same trees on the same area, it would be advisable to wait a year or two before planting. This does not refer, of course, to the replanting of unthrifty trees in an existing orchard.

(b) *Protective Covering.*

The fact that larvae cannot penetrate a dry, sandy surface prompted Mr. Jolles, of the Palestine Department of Agriculture, to try this as a prophylactic measure against *Capnodis*. This method is still in the experimental stage, and results are awaited.

(c) *Effects of Irrigation.*

In an earlier paper, it was pointed out that excessive moisture may affect the eggs of *Capnodis* and increase mortality. In the paragraph under the " Methods of Breeding," attention was drawn to the fact that larvae are also susceptible to excessive moisture. Especially is this true of neonate larvae which become turgid and cannot reach the roots in moist soil. In irrigated soils, mortality of larvae, whether neonate or old, is much greater than in non-irrigated soils.

(d) *Resistance of Trees.*

Irrigation of trees may have an indirect influence upon *Capnodis* by rendering the trees more resistant to the attack of the larvae. Irrigated trees may be more vigorous in growth, with the result that gum flows more freely from wounds. It was pointed out in an earlier paragraph that larval mortality in fresh pieces of almond wood was far greater than when the wood was allowed to wilt on account of the gum flowing from the wound. In this connection an experiment should be mentioned in which the writer, as early as 1936, tried to infest, artificially, strong, vigorous apricot trees. One hundred larvae were placed in wounds made in the roots of the trees. A week later the trees were examined. It was found that none of the larvae had succeeded in gnawing deep into the roots, and most of them were found drowned in the gum. A few had succeeded in penetrating a little deeper than the others, but none had survived. The same results were obtained in later experiments, when the writer tried to infest, artificially, two or three year-old almond trees. Although 25 larvae were introduced into wounds in the roots of these trees, none survived.

(e) *Resistant Varieties.*

No special study was made of the resistance of certain varieties to the attack of *Capnodis*, but from observations in the field and from rearings in the laboratory, it is evident that certain stock varieties of stone fruit trees are more resistant, while others are more susceptible. Mirobalan plum and apricots, for instance, are more susceptible to injury than bitter almond. The roots of apricots and bitter almonds were compared histologically, and it was found that the bark tissue of apricot is not so hard and compact as that of bitter almond, nor does it secrete as much gum as the latter.

It is, therefore, quite possible that resistance in a tree such as bitter almond depends upon the amount of gum secreted from injured cells in its roots. In other words, it depends upon the general condition of the tree or its physiological activities. As long as a tree is vigorous, and gum flows freely in the cambium wound, the tree is resistant. The lack of such qualities increases the susceptibility of the tree to injury. If this is true, one must not forget that the general condition of a tree depends not only upon hereditary characteristics, but also upon climate, soil, cultivation, and fruit-bearing conditions.

When planning an orchard, it would be wise to plant trees and varieties which are adaptable to the particular climatic characteristics of the neighbourhood.

A resistant variety may be more readily attacked than a non-resistant if it happens to be planted in an unsuitable soil. A clear illustration of this occurred in the grove of the Agricultural School at Pardess Hanna. In that grove, four varieties of root stock were planted, two rows of each, adjacent to each other. In the centre of the grove, a ridge of heavy soil ran through it, dividing the rows into two. This soil, for some reason, proved to be less suitable to the trees. It was found that trees which happened to be planted in it suffered heavily from *Capnodis*, regardless of variety, while in the better soil even non-resistant trees were not attacked.

In addition to the points of cultivation mentioned in the foregoing paragraphs, regular ploughing and fertilising create healthy vigorous trees which, in addition to the profit they yield, are resistant to many diseases and pests, including *Capnodis*.

It is a well-established fact that trees on all root stocks become more infested with *Capnodis* shortly after they begin bearing fruit. Even roots of bitter almonds, which are most resistant, may become infested at the beginning of the bearing period. The variety of fruit, also, which is grafted upon the root stock has a distinct influence upon the general welfare of the tree and subsequently upon its resistance to *Capnodis* injury, An interesting observation in this connection was made by Dr. R. M. Samish. At Sarid, in the Esd valley, Royal apricots were grafted on the same root stock—a local variety of apricots—as Blenheim, and both varieties were adjacent to each other and on the same type of soil. While the Royal bears heavily, the Blenheim in Palestine is a rather poor fruit bearer, but the Royal was injured by *Capnodis* more readily, and one by one the trees succumbed to their attack, while the Blenheim trees remained healthy and vigorous. When the Blenheim trees were topworked to Royal, they succumbed to *Capnodis* soon after the first heavy yield. Therefore, indirectly, the variety which is grafted upon the root stock may render the trees less resistant to *Capnodis*.

According to Samish, Ogden is the most resistant of the commercial plum varieties grown in Palestine, while Wikson is less, and Kelsey Beauty and Climax are the least resistant.

Summary.

(1) The methods of breeding larvae of *Capnodis* are described.

(2) A description of the larva and of its methods of locomotion is given.

(3) A study of the reaction of the larva to external stimuli is presented. It is pointed out that phototropic or geotropic reactions have no influence on the activity of the larva and that it is guided to its food through stereotactic and chemotropic reactions.

(4) The larva can detect roots or twigs from a distance of about 40 cm., and it can distinguish between the odour of various plants.

(5) Of various fruit trees, the odour of stone fruit was most attractive, and of these, almond comes first and apricots second.

(6) After the larva has located the root, and moulted, the sense of smell weakens gradually until it disappears. A comparative morphological examination of the antennae of neonate and mature larvae shows the olfactory organs are not present in the latter, while distinctly developed in the former.

(7) The larva feeds on the bark, tearing off minute particles, which it chews and finally discards.

(8) The tearing off of the fibres is facilitated by a fluid secreted from the mouth of the larva which softens the wood.

(9) Physiological tests show this fluid to contain a cellul~~o~~se, a pectinase and an amylase. a/

(10) Development from hatching to pupation at 33° C. lasts about 60 days, at 27° C. about 100 days.

(11) From empiric data it is apparent that the threshold of development is about 18° C.

(12) From measurements and calculations according to the law of Dyar, the larva must moult at least nine times before pupating.

(13) The larvae resist temperatures above 42° C. for eight hours, but die after a few days in such temperatures.

(14) Practical considerations for the fruit grower based upon this study are presented.

LYGUS SIMONYI, REUT., AS A COTTON PEST IN UGANDA.

By T. H. C. Taylor, D.Sc.
Imperial Institute of Entomology.

Introduction.

This review of investigations of *Lygus simonyi*, Reut., was originally written early in 1944 as a handing-over report, and was not intended primarily for publication. As I was then about to leave Uganda, it seemed desirable to place on record, for the information of my successors, the work which I and others had done, even though the investigations were still in an early stage. Since then, the opinion that publication of the report would be useful as a basis for future work has been expressed by the Empire Cotton Growing Corporation and others, and I have therefore agreed to publish it in spite of my consciousness of many shortcomings in it.

It has for some time been only too clear that there are no short cuts to the control of this very serious pest ; and that the attempt to solve the problem, or even to decide whether or not a solution is possible, requires full investigation of all aspects of it and involves the co-operation of plant-breeders, physiologists and entomologists. The problem must certainly be placed in the category of moderately long-term research, the scope of which will extend in Africa far beyond the boundaries of Uganda. I regard the work done hitherto, including my own, as little more than the necessary preliminary " spade work " ; and in these circumstances I thought it best to include in the report suggestions concerning all lines of future investigation which I myself intended to pursue, although some of them may appear at the moment to hold little prospect of success.

In its original form the report included an essential preliminary study of the male genitalia and other characters of about 20 species of *Lygus* which occur in Uganda. This systematic work was undertaken because it was evident that there had been much confusion in the past in the determination of the one species which was believed to be mainly responsible for the damage on cotton, and that until this species could be recognised with certainty in the field and in the laboratory all further investigation would be seriously hampered. This confusion no longer exists ; but my objective was limited, for practical reasons, to distinguishing all the species with certainty and did not include naming or systematic description of them. Almost all of the species were, and still are, referred to by letters only (Sp. A, Sp. B, etc.), and it is almost certain that most of them are new. It is now obviously desirable that description of all the new species, and determination and possibly redescription of the others, should be undertaken as soon as possible. For this purpose a separate paper is contemplated, and I have therefore omitted from the present paper that section of the original report which dealt with taxonomy. I have also omitted a section which deals with the host plants of all the species and which will be incorporated in the later paper, since its value will be greater when the insects have been named. Otherwise the report is still almost in its original form.

The cotton crop of Uganda is produced entirely by Africans in small plots scattered over the countryside, except in a few areas in which the communal system of planting has become established. In small plots the influence of surrounding vegetation is great, and in an investigation of this kind it is therefore necessary to study the insect in the countryside generally, not merely in the crop which it damages ; otherwise the conclusions reached are likely to be misleading or erroneous. I have endeavoured to make this aspect of the problem apparent in this paper. Another important point underlying the investigation is that most African growers are at present unwilling to co-operate in control measures which involve them in additional work, and this limits the measures which are practical to those which could be applied without direct assistance or conscious assistance from the growers.

The principal object of my work was to prevent or reduce the severe loss of crop which is caused annually by *Lygus* in the country as a whole. From the plant breeder's point of view, however, it is at least equally desirable and of greater immediate urgency to control or avoid *Lygus* on experiment stations. At present the insect causes such severe and uniform distortion of growth that it is exceedingly difficult for the cotton breeder to judge his plants and interpret his observations. I devoted very little attention to measures, notably chemical ones, which are unsuitable for application in small, scattered plots but which might be applied on experiment stations; consequently no reference is made to such measures although they might be of great benefit to the cotton breeder.

My predecessors in the study of *Lygus* in Uganda were Messrs. Hancock, Gwynn and Stephenson. References to their work are made at appropriate places in the text. Mr. H. D. Mubbiru (African Assistant) ably assisted all of us. I was fortunate in being able to discuss my work and conclusions at all stages of the investigation with Mr. H. Hargreaves, then Senior Entomologist in Uganda, whose long experience of African insects and special knowledge of Capsids have been invaluable to me.

Host Plants and Food Plants.*

The species of *Lygus* feed as nymphs and adults mainly upon flower buds, flowers, and developing seeds or fruits, but many of them (possibly all) also feed upon young leaf buds and young, developing stems. Older tissues, such as fully developed leaves and stems, are never attacked. The genus as a whole requires immature, rapidly growing tissues for food, and consequently the breeding of most species is largely confined to the wet seasons of the year.

Most of the species feed and breed on a great variety of plants of many unrelated families. The range of host plants is wide, and of food plants of adults very much wider. Nevertheless, each species has its own "preferences" as regards food and host plants although several species overlap in these respects. The condition of tissues is at least as important as the species of plant in determining the plants utilised at any particular time; and it follows that each plant species (except certain ubiquitous weeds which are in flower almost continuously) can serve as a source of food for only a short period, and that at different times of the year a species of *Lygus* has different food and host plants. In a country like Uganda which has rigid wet and dry seasons, a wide range of host plants is obviously essential for the survival of insects which can derive their food only from young, immature tissues.

The distinction between food plants and host plants is well exemplified by *L. simonyi*, which appears to have a much wider range of both than any other species. Its adoption of cotton as a host plant is not therefore surprising. It is the only species of *Lygus* (but not the only Capsid) which has adopted cotton as a principal host plant in Uganda. Its wide range of food plants enables it to survive the dry seasons in comparatively large numbers and to be distributed everywhere throughout the year. Adults are liable to be found on almost any plant species in open country, if one collects long enough, and it is probable that most of the plants on which adults are found can serve to some extent as food plants. But most of these are not true host plants, although the range of known host plants is wide and includes representatives of no less than fifteen plant families, many of them unrelated.

Of the twenty species of *Lygus* to which I have paid special attention, only *L. simonyi* is recognised as a pest of cotton. A few of the other species occasionally occur on cotton, but they do not breed on it and are negligible by comparison.

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* The term "host plant" is here used to mean a plant on which breeding occurs in the field; "food plant" is applied to one on which adults feed frequently and in numbers, but on which little or no breeding occurs.

Laboratory observations, to be referred to hereafter, indicate that *L. simonyi* may be found, on further study in the field, to damage other crops also, though it is not yet known to be harmful to any others except cow-pea (*Vigna*).

L. simonyi flourishes in both of the principal vegetational zones of Uganda, which may conveniently be termed the " elephant-grass " and the " short-grass " zones. The host plants mainly responsible for the large population in the countryside generally are cotton, certain grain crops, and numerous legumes (both cultivated and wild). It breeds principally on herbaceous plants, but also on several trees, and in the short-grass zone certain trees are probably the main sources of it during the dry season.

The known host plants, arranged in alphabetical order of families, are—

- ANACARDIACEAE.
  - *Mangifera indica.*
  - *Rhus glaucescens.*
- COMBRETACEAE.
  - *Combretum binderianum.*
- GRAMINACEAE.
  - *Eleusine coracana.*
  - *Sorghum* spp.
  - *Zea mays.*
- HYPERICACEAE.
  - *Psorospermum* sp.
- LABIATAE.
  - *Hoslundia opposita.*
  - *Ocimum* spp.
  - *Salvia* sp. (red fls.).
- LEGUMINOSAE.
  - *Caesalpinia sepiaria.*
  - *Cajanus cajan.*
  - *Cassia* sp.
  - *Indigofera* spp.
  - *Mucuna* sp.
  - *Phaseolus* sp.
  - *Pseudarthria* sp.
  - *Vigna catjang.*
- MALVACEAE.
  - *Gossypium* spp.
- MELASTOMACEAE.
  - *Osbeckia* sp.
- MELIACAEA.
  - *Melia azedarach.*
- MYRTACEAE.
  - *Syzygium* sp.
- PEDALIACEAE.
  - *Sesamum indicum.*
- PHYTOLACCACEAE.
  - *Phytolacca dodecandra.*
- STERCULIACEAE.
  - *Dombeya* sp.
  - *Waltheria* sp.
- VERBENACEAE.
  - *Lantana* sp.
- VITACEAE.
  - *Cissus* sp.

In most of these plant families there are many species which are known not to be host plants. The fact that only one or a few names appear under the families listed above does not mean that these were the only plants examined. Thus, in the GRAMINACEAE, only certain cultivated species having large flower-heads or seed-heads are host plants, and grasses in general are not. In the MALVACEAE, cotton is a preferred host plant, but other species (*Sida* spp. and *Hibiscus* spp.) are never attacked in the field in my experience. Moreover, certain important families (notably COMPOSITAE and EUPHORBIACEAE) appear to be wholly unsuitable for the breeding requirements of *L. simonyi*, although some other species of *Lygus* normally breed on certain plants belonging to them.

In most cases it is principally on the flowers, flower-buds or seeds that *L. simonyi* breeds. On cotton, however, the young vegetative shoots are at least equally attacked.

The food plants of the adults, as opposed to true host plants, include not only all the plants already listed but also a wide range of species in many other families. To list them would serve little purpose because the list would certainly be very incomplete, so great is the range. It appears that there are nevertheless several plant families (again the COMPOSITAE and EUPHORBIACEAE in particular) of which the species are avoided by adults for feeding as for breeding, though the insects occasionally occur on them as casual visitors or while seeking moisture.

Damage done by L. simonyi.

A. GENERAL EFFECT ON THE PLANT. Much has already been written on this subject, and the general effect on the cotton plant is well known. Hancock (1935) showed that a bad attack of *Lygus* causes holing, shredding, and distortion of the leaves, and also shedding of small squares (flower-buds) and terminal buds. All subsequent workers (Gwynn*, Stephenson*, Taylor) have confirmed these observations. It is now generally accepted that while the effect on the leaves is the most obvious form of damage and greatly weakens the plant when severe, the most serious damage is the shedding of squares and the killing of the terminal buds of branches. The latter effect limits the number of squares produced on the affected branches to those already formed before the death of the terminals, and may therefore be regarded as a loss of potential squares.

B. FIELD OBSERVATIONS, 1943. Two sets of observations were undertaken in the belief that an intimate acquaintance, week by week, with a few individual plants throughout their development is essential for the proper understanding and interpretation of large-scale field experiments which give their results indirectly through the mass collection of data.

1. *Maximum Damage.* The first set of observations was aimed at demonstrating the general nature of *Lygus* damage in its most severe form. Four similar young plants of the variety B.181 (*Gossypium hirsutum*) which showed no damage were selected in the field and two of them were stocked with 25 nymphs of *L. simonyi* each. The other two were kept as controls. A further batch of 25 nymphs was added to each of the first two plants at approximately fortnightly intervals until October. The plants were not enclosed in any way, but were isolated by the removal of neighbouring plants which might touch them. Otherwise the conditions to which they were subjected were the same as for all other plants in the plot, and the controls were attacked by *Lygus* to an extent which was usual for that year and which was severe as compared with a normal year. Complete diagrams of all four plants were prepared in September, and again in November when growth had ceased. Despite the fact that the controls were severely damaged, the differences between the two pairs were very striking. The important differences are listed below, the plants artificially stocked with *Lygus* being I and III, and the controls II and IV.

Plants I and III.	Plants II and IV.
Columnar in shape, owing to shortness of all branches.	Conical, the lower branches, including the lower sympodia being much longer.
Very ragged in appearance.	Much more normal.
Primary sympodia averaged 2.1 nodes.	Primary sympodia averaged 3.1 nodes.
Internodes on main stem and branches often very short so that leaves bunched.	Internodes mostly normal.
Many abnormal secondary, tertiary and axillary branches, all weak and useless.	Comparatively few abnormal branches.
No. of bolls that persisted was 6 and 4.	No. of bolls that persisted was 21 each.
All bolls unhealthy and useless ; crop completely destroyed.	At least 10 bolls per plant appeared healthy and likely to mature.

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* The important reports of A. M. Gwynn (1937) and P. R. Stephenson (1940) are unpublished and are available, in typescript, in Uganda only.

2. *Normal Damage.* The second set of observations was aimed at obtaining complete records of a number of plants under normal conditions in the field, to serve as a basis for comparison in future years and to find out more exactly what *Lygus* does to the plants week by week. For this purpose I chose a May-sown strip of the variety B.181 at Kawanda* (the early sowings always being more severely attacked), and selected and marked 60 plants which were not attacked when the observations were started in June. I hoped that a sufficient number of plants would remain unattacked to serve as controls and that the weather would be normal throughout the period of the observations. Unfortunately, neither of these hopes was realised. The *Lygus* attack was severe throughout the strip and not one plant escaped. Its severity was undoubtedly due to severe drought dating from the previous December, which upset the balance of insect populations generally. The weather continued to be abnormally dry until the end of the year, and at the end of October the rainfall was 11 inches below the seven-year average for the first ten months of the year. However, it was my intention that the observations should in any case be repeated in 1944 and 1945 to eliminate the effect of abnormal weather and to test conclusions, and now that I have completed the first series I feel that abnormally severe damage and drought during this first year may not, after all, have been disadvantageous provided one of the following years is normal.

It became apparent, as the plants grew bigger, that it was impossible to record more than 30 plants fully, and this is the number which should be adopted in future. The 30 plants chosen were distributed throughout the length of the middle row of the strip, and were recorded almost weekly from the end of June to the beginning of November, by which time growth had almost ceased.

Plant diagrams on cards were adopted as the method of recording. It was found necessary to make the records at frequent intervals in order that squares shed when very small should not be overlooked and that the true status of all branches should be definitely known. It frequently happens, for example, that a young sympodial branch is shed and is replaced by a monopodial branch in the same axil. Complications of this kind can be correctly interpreted only by thorough acquaintance with the plant every week.

On 26th June, when the 30 plants were selected, none of them had been attacked, but *Lygus* adults were already common in the strip and many other plants were showing damage. On the following day three of the marked plants were found to have been attacked (*i.e.*, they showed the usual spots on the youngest leaves), and a month later all except one (which was unusually small and hidden by others) had been damaged to some extent.

At the end of June, the plants were fairly uniform in size and condition. They had four or five nodes (excluding the cotyledon node) and no branches had appeared. A week later several of the plants had short branches, and from this time onwards the branches grew rapidly. The first flowers appeared in the first week of August. The *Lygus* population consisted almost entirely of adults at the end of June, but a month later nymphs were abundant. Both stages were plentiful throughout August, but there was a rapid decline in population during September owing to parasites, and by the end of September the attack had finished from the economic point of view. The period of attack was much longer than usual at Kawanda, owing to a second invasion of adults in August.

Very extensive shedding of young squares took place throughout the period of recording. It is certain that much of this was due to *Lygus*, but severe drought in July and early August, and again later, also caused shedding. Bollworms and stainers certainly played no appreciable part in the shedding that year, but the plants were weakened by a severe attack of *Aphis* in July.

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* An experiment station in the elephant-grass zone.

Although the full value of the weekly records cannot be assessed on one year's work, much useful information came to light. The diagrams showed every leaf, square, flower, boll and branch produced by each plant and the presence or absence of *Lygus* damage on every leaf produced. They also showed the subsequent fate of every part of the plant, and therefore provided information concerning not only the activities of *Lygus* but also the manner of growth of this particular variety of cotton; and this may prove to be of importance for comparison of damage on other varieties later.

The principal conclusions drawn from the 1943 records are detailed below :—

(*a*) In the middle of September, when *Lygus* had almost disappeared, the 30 plants had produced 1,282 leaves subtending squares (*i.e.* leaves on sympodial branches arising from the main stem and from the monopodia). Of these leaves, 893 or 70 per cent. had been damaged (not all severely) by *Lygus*. This serves to illustrate the cumulative effect of *Lygus* attack. Only the youngest leaves are attacked at any one time, but almost the whole plant is affected if the insect is present in numbers for two or more months. I have not actually totalled the figures for the monopodia but the diagrams showed that the leaves on them were damaged to a similar extent.

(*b*) In mid-September, 1,282 squares had been formed. 893 were subtended by damaged leaves and 598 or 66 per cent. of them had already been shed. 389 were subtended by undamaged leaves and 229 or 59 per cent. had been shed. The difference between the percentages is not great but I suggest that it is due to a tendency on the part of the insect to attack the square as well as the leaf at each node, in which case the former percentage will always be higher than the latter. If the difference is due to this tendency, it is safe to conclude that most of the shedding (64 per cent.) that had occurred at this time was primarily due to *Lygus*, though much "physiological shedding" would have taken place later in any case. In order to estimate the amount of shedding which took place amongst squares present when *Lygus* attack was at its height, the fate of all squares recorded to the end of July was followed in later diagrams. It was found that out of 212 squares produced up to that time, 170 or 80 per cent. were shed sooner or later. It is almost certain that nearly all these *early* squares would, in the absence of *Lygus*, have become mature bolls.

(*c*) When the final records were made in November the total number of squares that had been produced was 1,559. The total number of bolls on the plants was 305 (which is 19 per cent. only of the squares produced) and the number per plant therefore averaged 10·2. Many of these were diseased and weak, and certainly would not have produced any crop; and it is likely that the number which would have matured normally did not exceed 6 per plant on the average. The number of squares produced and the number of bolls present in November varied from 6 to 131 and 2 to 31, respectively, per plant.

(*d*) On the monopodia, 24 per cent. (108 in 457) of the squares produced were bolls in November. The corresponding figure for the sympodia was 18 per cent. (197 in 1,102). The difference is considerable. Possible reasons for it are discussed on page 144.

(*e*) Nearly all the sympodia ceased growing early in September, with the result that no more squares were produced on them (except on secondary branches). This was because the terminals of most of them were dead. Very many of the terminal buds were killed by *Lygus*, but the weather was so unfavourable that the relative importance of *Lygus* in this connection cannot be judged. Another year's observations may settle this important point.

(*f*) After the terminal buds of the primary sympodia had been destroyed, numerous secondary and tertiary branches appeared on the sympodia, and monopodial axillary branches grew from the main stem. I regard most of these as abnormal and attribute them to the loss of the terminals. They have little or no value because they are weak, and although they produce squares and bolls these are themselves weak and rarely develop normally. It may be worth while recording that the branching induced by *Lygus* was almost always alternately monopodial and sympodial. That is to say, a primary sympodium produces monopodia, which in turn produce sympodia ; and in the case of a primary monopodium the sequence is reversed. Similarly, an axillary branch on the main stem from a node which has already produced a sympodium is monopodial and itself produces sympodia. A plant which has not suffered severely from *Lygus* does not carry its branching to the tertiary and quarternary stage to any great extent, and therefore does not so clearly demonstrate this.

(*g*) The variety B.181 is mainly sympodial in habit. The cotyledon node rarely produces branches, but occasionally two opposite monopodia grow from this point and these may attain a length of 10 nodes and produce squares and bolls on their branches. The first node above the cotyledons, which was called A in the diagrams, invariably produces a monopodium, as do B and C. Branch D is usually monopodial but sometimes sympodial. E is occasionally monopodial but is usually sympodial, and all subsequent branches are nearly always sympodial. The average plant has only two large monopodia (C and D), the first two (A and B) being short and weak. The method of branching has a bearing on the amount of early shedding.

(*h*) Although nearly all the sympodia had lost their terminals by September those of the monopodia were retained (with few exceptions), as was the apical bud of the main stem (also with few exceptions). In fact, the main stems and the monopodia almost all continued growing until November. In the rare cases in which the main stem terminal died, the cause was bollworms, not *Lygus*. (The loss of the main stem terminal results in extensive growth of the secondary axillary branch, not the primary, from the highest remaining node. This replaces the lost terminal and grows vertically, and being derived from the second axillary bud, it is monopodial and therefore difficult to distinguish from a normal main stem unless the history of the plant is known.) Reasons for survival of the terminals of the main stem and monopodia are discussed on page 144.

(*i*) The first squares are produced on sympodia, although the monopodia grow out before the sympodia. On the evidence at present available, it is estimated that the first square on a sympodium appears at least 2 weeks, and probably 3 weeks, before the first on a monopodium.

(*j*) The shedding of almost all the earlier squares delays bulk flowering and consequently delays the maturing of the crop. The first flowers on the 30 plants opened on August 10th (*i.e.* 11½ weeks after sowing). There were only two of them, on different plants, and each resulted from the first square to appear on its plant (*i.e.* the first square of the lowest sympodium). On most of the other plants this first square had already been shed, and it was not until about 3 weeks later that most of the plants had produced at least one flower. Bulk flowering did not begin until mid-September, corresponding to the decline of *Lygus*. It was delayed by *Lygus* for about a month. I believe the flowering peak was delayed considerably longer (probably about 6 weeks), but my records are not such as to demonstrate this.

(*k*) The absence of controls for the 30 plants, due to 100 per cent. infestation, was unfortunate. It is profitable, however, to compare them with plants of the same variety in a nearby strip which was sown on June 20th (*i.e.* one month later), and therefore avoided half of the period of *Lygus* attack. In early October, ten plants chosen at random in the middle of this strip were mapped on cards in the same way as the 30 May-sown plants. They were then compared with the latter at the same stage of growth, as estimated by the number of nodes on the main stem. The ten plants averaged 16·8 nodes, and the 30 had averaged the same number early in September.

The total number of squares already produced by the ten plants was 300 (mean 30 per plant) and the number shed was 76 (mean 7·6) or 25 per cent. The 30 plants* produced 973 (mean 34·7 per plant) and the number shed was 499 (mean 17·8) or 51 per cent.

A further comparison was obtained by counting in November the number of squares produced and bolls which persisted on one sympodium (branch G) of 20 plants selected at random in the same June-sown strip. These 20 plants averaged 3·6 squares and 1·6 bolls for this branch, whereas the 30 recorded plants averaged 3·2 squares and only 0·4 bolls. That is to say, 44 per cent. of the squares on this branch produced bolls in the June-sown strip and only 14 per cent. in the May-sown.

Although the June-sown plants cannot strictly be regarded as controls owing mainly to the difference in sowing-date, they do nevertheless give a good picture of the difference in effect between an attack of *Lygus* lasting 2 months and one lasting one month. I am sure that the differences in the figures that I have given are due mainly to *Lygus*, and that they would have been much greater had true controls, not attacked at all, been available.

(*l*) The 30 plants were markedly inferior in all respects to a few other isolated plants in the same strip which were growing in places where the soil was deeper through having been accidentally heaped up during cultivation. These few plants, which showed severe leaf damage and were exposed to *Lygus* attack to the same extent as all others, were so different that they could immediately be noticed from a distance. This difference is attributable to the stronger and more rapid growth of plants in deeper soil. These were the only plants which did not suffer severely from drought when they were young, the longer roots presumably having enabled them to make more use of the available water supply.

C. SIGNIFICANCE OF PARTS OF PLANT ATTACKED. *L. simonyi* attacks only the young and succulent tissues of the plant, notably young, unopened, leaf buds and minute flower buds. A leaf is liable to be attacked for a short time after it has unfolded, but it becomes unsuitable for *Lygus* long before it is fully grown. Stems, even when young and succulent, are rarely attacked. When the plant is older and growth has almost ceased, very small bolls appear to be preferred ; and at a still later stage, when growth has stopped completely in dry weather, the whole plant becomes unsuitable as food and both feeding and breeding cease.

It is important to realise that although every leaf and square throughout the plant is liable to be attacked, each individual part is susceptible to attack for only a very short time. As soon as this short period is passed, each leaf and square is almost immune from attack, and therefore the plant as a whole at any one time may be said to be largely resistant to *Lygus*. If we can produce a variety of cotton that grows and opens its buds more quickly, the susceptibility to damage is reduced. Or if we can produce a plant on which the hairs, before they are separated by growth, afford protection to the buds, or a type of plant on which the hairs, after separation by growth, make it difficult for the nymphs to reach the buds, then again we reduce susceptibility. Yet another possibility is the protection of terminals by monopodial growth ; that is, by surrounding them with the buds of developing secondary sympodia and by providing so many sympodial buds on every branch that the nymphs have no need to visit the terminal bud in particular. All buds are equally susceptible to damage, but some are of much more importance as regards crop than others.

Since yield is the ultimate criterion of damage, leaf damage is relatively unimportant except in extreme cases. Damage to squares, resulting in shedding, is more serious, and damage to terminals, resulting in cessation of growth, is more serious still since each terminal represents several squares. In seeking resistance, therefore, primary consideration should be given to the terminals, unless indications are obtained that some chemical or physiological factor inherent in the plant as a whole can be utilised.

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* The figures for these are based on 28 of the 30 because two were diseased and abnormally small

D. REACTION OF TISSUES TO *LYGUS* ATTACK. The immediate result of the attack on young, succulent, tissues of cotton is the appearance, within only 3 hours, of small blackish spots. The cells within the area of each spot are dead, and as the affected part grows a ragged hole appears. If the spot is on a leaf, it is often bounded by small veins and therefore has an angular outline. This means that the mechanical or toxic action cannot penetrate the veins, though in a concentrated attack many contiguous spots may be formed and result in a considerable area of a leaf dying.

The question as to whether the death of the tissues is due to mechanical or toxic action has been much debated and is not yet solved. It is obviously important in connection with an attempt to evolve resistant varieties. The only concentrated attempt yet made to solve it is that of Stephenson, whose work ceased while still in the preliminary stage in consequence of the war. Stephenson expressed the tentative conclusion (after careful experiments which, however, he was prevented from repeating and extending as he intended) that the saliva of *L. simonyi* is acid and that the discoloring of the tissues might be due to "a breakdown of the middle lamellae of the cell walls". My own observations have led me to the view that the damage is more likely to be primarily mechanical and that the discoloration is due to secondary toxic action. The stylets, which are bent at the point of entry into the tissues, are often withdrawn and reinserted at the same point but probably on a different radius, with the result that many cells are ruptured and sucked around the point of entry. It seems probable that a certain amount of maceration of tissues, in addition to direct puncturing, results from the passage of the stylets.

I paid attention to the importance of water as a factor which renders the tissues susceptible to damage by *Lygus*, having often noticed that in dry weather the spots resulting from *Lygus* attack are exceedingly small and do not cause appreciable holing or tearing as the leaves grow. It was found in the laboratory that young shoots of cotton are severely damaged only if they are maintained in high humidity and with their stems in water. If the container has cloth or gauze sides, the damage is slight, and often nil in dry weather. If the container is a glass cylinder, in which the humidity approximates to 100 per cent. so that moisture precipitates on the glass, the damage is very severe. Moreover, in the former case the insects die in three days and wander incessantly, making stabs at the tissues without penetrating them ; whereas in the latter case they live much longer and feed almost continuously, without wandering. I conclude that a high water content is essential for normal feeding and that the insect is actually unable to feed properly unless the tissues are highly turgid. Whether the turgidity is itself the determining factor is another matter, but this seems quite likely. We already know that "succulent" cotton plants show more leaf damage than their "drier" neighbours. This might be due to many factors other than water content, but at the moment I see little reason to look further for an explanation.

The species of *Lygus* commonly known as "Green Lygus" (*i.e.* my Sp. C), which feeds on cotton in the field but does not breed on it, causes precisely the same leaf damage in the laboratory as *L. simonyi.* But in this case also the damage occurs only when the cotton shoots are saturated with water (which explains the failure of some other workers to obtain any reaction with this species). Incidentally, since the range of host plants (as opposed to mere food plants of adults) of Sp. C differs very greatly from that of *L. simonyi*, one would expect the two species to cause different reactions in cotton if the damage were not primarily mechanical.

All varieties and species of cotton (including woody perennial species) tested by me in the laboratory react in precisely the same way to the attack of *Lygus* ; in all cases, spots appeared on the leaves in a few hours, always provided that the tissues were saturated. And very severe spotting of the leaves developed in *Hibiscus rosae-sinensis* (the common double red form) in very humid conditions, although this plant is never attacked in the field so far as is known. Numerous other species and genera of plants which were tested gave no results, but in all these cases the *Lygus* nymphs used did not attempt to feed to any extent on the leaves and soon died, so that it is impossible to say what would have happened if they had fed. The leaves of *Abutilon indicum* and a bean (*Phaseolus*), however, reacted strongly when saturated, and developed spots of dead tissue which resulted in the leaves becoming ragged in the usual way as they grew. But in these two cases no discoloration took place (until the tissues became brown through drying), and the spots were semi-transparent and were not readily visible unless the leaves were held up to the light.

It is suggestive that even in the absence of discoloration the damage is the same; the *Abutilon* and *Phaseolus* shoots which were tested with *Lygus* shed their young buds, while other shoots kept as controls shed nothing.

Many other Capsids cause damage on various plants similar to that caused by *L. simonyi* on cotton. Examples are: *L. pabulinus*, L., on various fruit trees and other plants in England (Petherbridge & Thorpe, 1928); *L. elisus*, Van Duzee, on cotton and lucerne in U.S.A. (McGregor, 1927); *L. pratensis*, L., on various plants in several countries; *L. coffeae*, China, *Volumnus obscurus*, Popp., and *Lycidocoris mimeticus*, R. & P., on coffee in Uganda (Hargreaves, 1940); *Helopeltis bergrothi*, Reut., on tea, cotton and other plants in Uganda (Hargreaves, 1940). All these Capsids cause the death and discoloration of the tissues around the point of attack. In the case of *Lycidocoris* and *Helopeltis* there are strong indications that the damage is primarily mechanical.

E. METHODS OF COMPARING DAMAGE. The method employed in Uganda for comparing *Lygus* damage in field experiments consists in assessing the damage on the five topmost leaves of the plant on a scale in which the units are arbitrary. The method was initiated by Gwynn and has now been used for many years. It has many serious disadvantages, as Gwynn himself admitted, but there is no better method for use in experiments which require the collection of data from a large number of plots and plants in a short time.

The principal objection to this method is that it is based on leaf damage only and takes no account of the damage which results, directly and indirectly, in loss of crop. It seems likely, in consequence of experience with individual plant records in 1943, that one of the lower sympodia (say the third from the bottom) might be used with advantage as a means of comparing damage to crop. The number of nodes on the sympodia gives an accurate idea of extent of damage in a plot as a whole. In the 30 plants it varied from one to seven for branch G. An additional advantage of this method would be elimination of the personal error, since it would involve a straightforward count and no judgment. Its principal disadvantage would be that it could not be used for monopodial types of plant, but neither could the leaf-damage count with fairness because the frequency with which the nymphs visit the apical bud varies with the type of branching.

The fact that the basis for comparison of varieties has always been leaf damage only makes it necessary to interpret all results so far obtained with some degree of caution. In almost all reports written hitherto the term "*Lygus* damage" means "*Lygus* leaf-damage."

The assessment of damage by means of a node count presupposes that *Lygus* completely outweighs other factors in determining the length of sympodia. This is, I think, a sound assumption, but my programme for 1944 included a survey of the causes of shedding of terminals following some preliminary observations made in 1943.

Damage done by other Capsids.

A. *Lygus Sp. C* ("*Green Lygus*")*. In another section of this report I have recorded the fact that in humid conditions in the laboratory this species causes the same damage as *L. simonyi*. In my experiments, which were repeated, the reaction of the cotton plant (B.P.52) was very severe, and I feel certain that in wet weather or when there is ample moisture in the soil, the same reaction must occur in the field. In the elephant-grass zone this species is always a rarity on cotton. But in the drier areas, for a short time after the harvesting of grain crops, it is far more common on cotton than *L. simonyi* and must cause considerable damage at the time when the plants are young and damage first appears (July and August). However, since it scarcely breeds on cotton and there is no second invasion, the damage is not cumulative as in the case of *L. simonyi* and is therefore negligible by comparison. But in any special observations which may be made at the time of the initial invasion from grain crops, this species should certainly be taken into account.

Its range of known host plants is unusually small. It breeds abundantly on sorghum, but not on *Eleusine*. Cotton scarcely serves as a host plant, and the only other plant on which I have obtained nymphs is *Cedrela* sp. (Meliaceae) on which it breeds on the flowers. Adults are common on a variety of inflorescences, notably (so far as my records go) *Mangifera indica* and *Euclea* sp.

B. *Megacoelum apicale*, Reut. In humid conditions in the laboratory this insect causes great damage to the shoots of cotton plants. The damage consists in the shedding of young leaf and flower buds and particularly of the terminals. This is due to the sucking of the minute, succulent, stems of these parts by the insect. No spotting of the leaves occurs in any circumstances, and I believe *Megacoelum* never feeds on leaves. It is mainly an insect of the flower buds and young bolls, but is often seen feeding in the field on young, developing stems in the terminals, when the plants are young. It seems likely that the method of feeding differs from that of *Lygus*, and that the stylets of *Megacoelum* are thrust into thick tissues without bending, while those of *Lygus* are inserted commonly into thin parts (usually leaves) and bent at the point of entry. It would be worth while to test this by killing the insects with the stylets *in situ*.

I am unable to say exactly what damage *Megacoelum* does in the field. On bolls it causes small, circular, black spots, usually sunken in the centre, and probably the interior of the boll is affected also. I strongly suspect that it causes the shedding of terminal buds in the field, as in the laboratory, and this is a point that requires investigation. Preliminary field experiments in 1943 indicated that it causes shedding of squares.

Megacoelum breeds abundantly on cotton, and also on the flowers, flower buds, or immature seeds of sorghum, *Eleusine*, maize, *Ricinus*, *Cupressus*, *Cajanus*, and *Abutilon*. Like *L. simonyi*, it has a very wide range of unrelated host plants; but it is interesting to note that although many plants serve for both insects, their requirements are not the same, for *L. simonyi* never breeds (in my experience) on *Ricinus*, *Cupressus*, or *Abutilon*.

Megacoelum first arrives in cotton early in the season, with *Lygus*, but it does not immediately begin breeding on a large scale. In fact, no extensive multiplication occurs until the plants are much older and have many flowers. The result is that the peak for the *Megacoelum* population in cotton is about a month later than that of *Lygus*.

C. *Other Capsids*. *Corizidolon* sp. and *Sthenarus* (2 spp.) are common on cotton, but in laboratory experiments neither did any damage of any kind. Both breed on cotton. The principal host plants of *Corizidolon* sp. are leguminous (*Crotalaria Cajanus*, etc.). *Sthenarus* spp. are often common on the same legumes, but also on a great variety of other plants.

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* To be described in a separate paper.

Natural Enemies.

The natural enemies of *L. simonyi* in Uganda include spiders, predatory Capsids of the genus *Deraeocoris*, Hymenopterous parasites of the genus *Euphorus*, and probably egg parasites of the family MYMARIDAE. Of these, the only ones that appear to be of great economic importance are two species of *Euphorus*, a genus which belongs to the sub-family EUPHORINAE of the family BRACONIDAE. The few species of *Euphorus* and the closely allied genus *Euphoriana* of which the hosts are known all attack Capsids. The economic status and potentialities of the two *Euphorus* spp. which parasitise *L. simonyi* in Uganda are discussed elsewhere in this report ; I propose here to outline their habits only.

These two species of *Euphorus*, both of which have been generically determined by the Imperial Institute of Entomology, are designated in my collection of parasitic Hymenoptera and in my notes as T.801A and T.801B.* They are very similar in habits, appearance, morphology, and distribution in Uganda. Both frequent open country, not forest, and both occur in the elephant-grass zone and in the hotter short-grass zone.

The range of hosts is the same for both, judging from my records, and includes "*Lygus* Sp. D" on composite weeds ; *L. simonyi* on cotton and sorghum ; "*Lygus* Sp. C" on sorghum ; "*Lygus* Sp. A" on *Ricinus ; Deraeocoris* spp. on cotton and *Cajanus ; Megacoelum apicale* on cotton, sorghum and *Ricinus ; Corizidolon* sp. on cotton ; *Stenotus* spp. on grasses. I have reared T.801B from *Eurystylus* sp. on *Ricinus* and have little doubt that T.801A also attacks it. It is clear that both parasites have a great variety of hosts among Capsids, that both frequent a great variety of herbaceous plants in search of their hosts, and that consequently they can be expected to be present in almost any locality where cotton is planted. The plants frequented by them, however, are not all the same in different types of country, for at Kawanda both species attack *L. simonyi* and other Capsids abundantly on cotton, while at Serere† neither attacks any Capsid on cotton except as an exceedingly rare event, although both are common in certain other hosts close to cotton plots. Further, although the host range is wide there are certain Capsids on cotton and other plants which are never attacked by them. The two species of *Sthenarus* which abound on many plants, including cotton, have their own species of parasites of genera closely related to *Euphorus*, but they are never attacked by either T.801A or T.801B.

The eggs of both species are always laid in nymphs, usually in very small nymphs. They appear to be unattached in the host body and are readily freed if the host is dissected in water. In shape they are broadly ovoid and I have seen no trace of a stalk or appendage, but I have not studied them in detail. Occasionally, when the parasites are very numerous as compared with the hosts, eggs are laid in large nymphs, but this is abnormal.

The young larva is of the mandibulate, caudate type. Its presence has no apparent effect upon the host, which continues feeding and growing until it attains the last nymphal instar. When this is the case, the parasite larva is normally full-grown, and it leaves the host by breaking through the skin at the side of the abdomen. In the rare instances of eggs laid in large nymphs, the parasite larvae escape from adult hosts before the host cuticle has completely hardened. The host does not die until about one day after the emergence of the parasite from it.

Only one egg is laid at a time in each host individual, and only one parasite can develop in each. When the adult parasites are plentiful several eggs are often laid by different parasites in one host and I have found as many as five larvae in one large nymph, but in such cases only one becomes fully grown.

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* Descriptions of these and of other EUPHORINAE referred to in this section will be published in a paper which Mr. G. E. J. Nixon is kindly preparing.

† An experiment station in the short-grass zone.

The parasite larva almost invariably emerges from its host in the early morning. It immediately proceeds to spin a white, spindle-shaped, cocoon which is broadly and irregularly corrugated longitudinally. Since the larva drops from the host on emergence the cocoon is presumably formed in the soil or amongst dead leaves on the surface.

The emergence of the adult from the cocoon also occurs early in the morning. Males are relatively scarce. When the sexes are paired off in tubes, copulation occurs on the day on which the adults leave their cocoons. The duration of adult life (both species and both sexes) is comparatively long, judging from laboratory tests in which 12 specimens were kept singly in glass tubes and fed on honey. It varied for 11 females from 19 to 38 days (mean 30 days) and for a single male it was 26 days.

The period spent in the cocoon varies from 12 to 21 days according to temperature, but the normal variation is from 14 to 17 days, the mean being 15 days. The life cycle from oviposition to emergence of the adult has not been determined with accuracy, but is likely to cover about a month.

An Ichneumonid of the genus *Mesochorus* parasitises T.801A, T.801B, and other Euphorine parasites of Capsids. It is a purely secondary parasite. It occasionally becomes common as a secondary parasite of *L. simonyi* on cotton via T.801A and B, but not until the latter have themselves become so abundant as to suppress their host. I attach little economic importance to it. (It is T.802 in my collection and records.)

In the course of a survey of the alternative hosts of the parasites of *L. simonyi*, several other primary parasites of other Capsids were discovered. All of them belong to the EUPHORINAE. T.803 parasitises *Sthenarus* nymphs on cotton and forms a white cocoon which is not corrugated. T.803A attacks *Deraeocoris* nymphs, and also forms a white cocoon without corrugations. T.866 is abundant as a parasite of nymphs of "*Lygus* Sp. D" on *Erigeron*, and has also been reared from nymphs of "*Lygus* Sp. T" on *Basella*; its white cocoon is corrugated. T.959 is a parasite of *Engytatus* nymphs on *Gynandropsis*. T.967, which is a *Euphorus*, attacks nymphs of "*Lygus* Sp. T" on *Basella* and forms a cocoon identical with those of T.801A and B; it is probably a forest species. T.1073 was reared from Capsid nymphs (mainly *Stenotus*) on elephant-grass. T.957 attacks nymphs of *Nysius* (Lygaeidae) on *Erigeron*, *Vernonia*, and other composites.

In my experience none of these other parasites ever attacks *L. simonyi*. Their principal economic importance lies in the necessity for distinguishing them from T.801A and B, and their hosts (as nymphs particularly) from *L. simonyi*, in order to avoid confusion. In large collections of nymphs of *L. simonyi* or *Stenotus* one or more of them is liable to be present owing to the accidental inclusion in the collections of Capsid nymphs other than those intended.

The Course of the Annual Infestation at Kawanda in the Elephant-Grass Zone.

This account of the development and decline of the annual outbreak of *L. simonyi* at Kawanda applies in all essentials to all areas in this part of the elephant-grass zone of Uganda. The only important difference is that the attack is not usually so severe in the small, isolated plots in which the Africans grow cotton as in the much larger areas of an experiment station like Kawanda. I attribute this difference to a tendency for a higher proportion of the insects to disperse from small plots than from large ones, so that the immigrants tend to accumulate in the latter so long as the movement of adults continues. This is pure surmise, but the same conclusion was reached by Gwynn at Serere.

The sequence of events as here described is based on only two years of close study. It is possible, therefore, that the dates given may not be quite correct for all years.

It is convenient to begin this account at the beginning of the year, when no young cotton plants are present and harvesting of the crop is being completed. The weather is dry and hot, and all host plants of *L. simonyi*, both wild and cultivated, are in a condition which does not allow the insects to breed to any great extent. Consequently the population is low and consists almost entirely of adults widely dispersed on a great variety of plants, many of which serve as sources of food for adults but are not host plants. In February it is exceedingly difficult to find the insects, even by sweeping and beating, but diligent search yields a few any day. The available evidence indicates that at this time leguminous plants are the principal source of food, but even these are not in a condition which permits breeding, except one or two individual plants of each species which happen to be growing in more favourable situations as regards moisture. The more important legumes in this connection are probably *Cajanus*, *Pseudarthria*, *Crotalaria*, and *Indigofera*. With the exception of *Cajanus*, these often grow in the shelter and partial shade of elephant-grass, and in such a situation *L. simonyi* is liable to be found.

The parasites that attack *Lygus* are not so adversely affected by the dry weather. In fact, they have no difficulty whatever in surviving and continuing to breed, because certain of their other host insects themselves survive and breed without difficulty. Of these other hosts the most important are *Lygus* Sp. D on a variety of composite weeds, and *Stenotus* spp. on the flowers of various grasses, notably *Brachiaria* spp. and *Pennisetum*. The general distribution of the composites (*Conyza*, *Erigeron*, *Senecio*, *Vernonia*, etc.) and of grasses causes the parasites to be present everywhere in large numbers, and this is of great importance in connection with subsequent developments in cotton.

Extensive sowing of cotton begins in May, though much more is sown later. By this time *L. simonyi* has multiplied greatly, the rains of March and April having provided it with succulent growth, including flower buds, on very many different host plants. Clumps of *Pseudarthria* growing in elephant-grass, *Cajanus* on cultivated land, *Lantana* and *Verbena* near habitations, various flowering trees, isolated patches of sorghum, and many other plants, are all supporting large populations of *L. simonyi* in all stages. At this time there is no tendency whatever for *Lygus* to spread from these plants, and the small amount of cotton sown earlier than May for experimental purposes at Kawanda remains completely free from it throughout May and part of June, although it is in a highly susceptible condition. In the middle of June, however, some migration of *Lygus* begins and a few scattered cotton plants in the May-sown plots, and also in plots sown earlier, are seen to be attacked. This is the absolute beginning of the *Lygus* outbreak on cotton, and at this time all the May-sown plants are still very small, none of them having more than three nodes. The reason for this migration is that by the middle of June many of the other host plants are beginning to dry out. In each plant species, some individual plants are still entirely suitable for *Lygus*, but others are not. There is no mass migration like that which occurs in the drier parts of Uganda outside the elephant-grass zone (see page 137), because there is no sudden harvesting or disturbance of any of the principal host plants. Grain crops do not dominate the countryside, and are actually very few and far between. The migration process is merely a gradual spreading of adults in all directions, resulting in a steady infiltration into cotton plots and all other plots and places. But those individuals that find themselves in cotton plots tend to remain there temporarily because the plants are in an ideal condition for both feeding and oviposition. The first eggs are laid immediately, and the first nymphs appear before the end of June but are still very scarce and minute. Until the end of June the percentage of plants showing damage is low (less than 10 per cent.) and almost all the damage is due to wandering adults.

At about the beginning of July the bulk hatching of eggs begins and some nymphs are already large. The percentage of plants showing recent damage and the severity of damage both increase with remarkable rapidity and both reach a peak at the end of July, when almost every plant in the May sowings is severely damaged, though not all have *Lygus* on them at any one time.

Meanwhile, the June sowings have germinated and the plants have become suitable for *Lygus*. The spread of *Lygus* continues, but to a decreasing extent, throughout July. The June-sown plants are attacked and some are badly damaged, but on the whole the attack is much less severe.

The *Lygus* individuals which attack cotton in June are followed very quickly by the parasites, especially if, as at Kawanda, the cotton strips are bordered by strips of elephant-grass which contain several hosts of both species of parasite. By the beginning of July, many nymphs are already parasitised and by the end of July (only about 6 weeks after the commencement of the *Lygus* attack on the cotton) parasitism is almost complete (98 per cent.). That is to say, although nymphs are abundant at this time and doing great damage, almost all of them fail to become adult and to reproduce. This is one of the most striking examples of biological control that I have seen. It naturally results in a very sudden and drastic reduction in damage and in the *Lygus* population. Unfortunately, however, the movement from other host plants, in which parasitism is never so high (see page 145), continues, and *Lygus* continues to arrive in the cotton throughout August. Consequently damage is still done despite almost total parasitism in the cotton.

In a normal year, so far as I can judge at present, there is only the one peak for *Lygus*. This is at the end of July. The population of adults then steadily decreases because during August the other sources of the insects are steadily drained by migration as the plants dry out and all nymphs are parasitised continuously. In mid-September there is little *Lygus* anywhere and no further movement of adults occurs. In abnormally dry years like 1943, however, dry weather in July and the first half of August causes abnormally rapid maturing of the wild host plants and therefore abnormally concentrated migration of *Lygus* at the end of August. Thus, in 1943 there was a second peak for *Lygus* damage at the end of August owing to invasion of the cotton by unusually large numbers about the middle of the month.

Parasitism in nymphs remains almost at the 100 per cent. level continuously from the end of July onwards, so that all the progeny of the immigrants in August fail to become adult, and the whole outbreak ends when the migration ceases. Wet weather in September does not cause a second outbreak because there are no more adults to migrate and parasitism is still complete. All cotton sown in July and later is therefore completely protected and is scarcely attacked at all. If it were not for the parasites, an enormous population would develop in the earlier sowings and prevent them from producing any crop whatever, and the later sowings would suffer very severely by migration from the earlier ones. As it is, only the May sowings are very badly damaged, and even these usually produce a useful late crop.

So long as *Lygus* nymphs are present in the cotton, the parasites attack them in preference to *Megacoelum* which is abundant in September. The reason for this is, I believe, that most of the *Megacoelum* nymphs, unlike *Lygus*, are hiding under the bracts of squares and bolls and are relatively inaccessible ; but as soon as *Lygus* disappears, the parasites, which are present in vast numbers by this time, are compelled to search more diligently for hosts and the parasitism in *Megacoelum* rises in consequence. In 1943, the parasitism in the latter steadily increased throughout September and October, and was almost complete in the third week of October.

During the last two months of the year, the position as regards *Lygus* is much the same as in the early months. Adults are scarce and scattered, mainly owing to parasitism in nymphs over a long period. Many wild plants are still suitable as food for adults, but breeding is limited by the age and increasing dryness of many of the true host plants. All cotton plants are now old and unsuitable for *Lygus*, but slight breeding continues on cotton till the end of the year, especially if rain increases the succulence of the plants. In December it is still possible to collect a few nymphs by sweeping in the latest sowings, and these are always heavily parasitised. The percentage parasitised, however, is not usually above 50 at this time, but this relatively low percentage is merely due to the scarcity of hosts. It is a general rule that parasites cannot attain a high percentage parasitism when the host is scarce, except in special circumstances.

In 1943 a weekly count was made of the plants showing fresh *Lygus* damage in a middle row of a May-sown strip at Kawanda. Only those plants that had new spots on the youngest leaves were counted on each occasion. This count gives a good idea of the rise and fall in *Lygus* incidence and damage throughout the season. The row counted contained 1,035 plants (*i.e.* " holes ", not individual plants) and the weekly counts are given below :—

24 June	29	23 August	417
1 July	72	2 September	682
8 July	241	13 September	601
15 July	438	23 September	417
22 July	663	30 September	203
29 July	734	7 October	152
5 August	591	14 October	9
12 August	479	22 October	3

The two peaks are very obvious, but as I have said, I think the second is abnormal and a normal year would show a steady decline from the end of July onwards. The sudden drop at the end of July marks the attainment of total parasitism in nymphs.

(All references to parasitism which I have made in this section are based on periodic and frequent dissections of nymph samples. Most samples contained 100 nymphs, and none less than 50. Dissection immediately reveals the presence of parasite larvae or eggs, and can be done very rapidly with a little practice.)

The Course of the Annual Infestation at Serere in the Short-Grass Zone.

The damage done by *Lygus* in the hotter and drier areas of the east and north (but not the extreme north-west—*see* page 146) is annually more severe than in the elephant-grass zone. Moreover, there are important differences in the causes and course of outbreaks in the two areas, and consideration of these gives clues to possible control measures. In these circumstances, it seems desirable to outline separately the annual sequence of events at Serere, as I have done for Kawanda. Serere is representative of the drier areas, except that the damage on the experiment station is greater than in most other plots, probably for the reason given for Kawanda.

Gwynn's valuable report (unpublished) gives a good account of many aspects of the Serere outbreaks, and I hesitate to trespass on ground that has already been covered by him. I do so only because information obtained since his departure fills gaps in his story and because it is desirable, in order that the difference between Serere and Kawanda may be fully appreciated, to set out the principal events at Serere in the same sequence as for Kawanda.

Beginning, then, in the early months of the year when all cotton has been harvested and there are no young plants suitable for *Lygus*, the population consists mainly of adults that are scattered in the bush and in the vegetation of resting land. Little breeding occurs and the insects are nowhere concentrated. Sweeping low vegetation in the bush (in various localities besides Serere) usually yields none ; and my impression is that at this time various flowering trees and bushes are the principal means of survival of *L. simonyi*, partly because their inflorescences provide food and partly because of the moisture, shelter, and shade which they afford. Some of these are common in the bush, while others are grown near habitations. Examples are *Mangifera, Combretum, Rhus, Psorospermum, Cadaba, Cedrela, Syzygium, Melia,* and I have no doubt there are many more. On the flowers of most of those named, nymphs* have been found in February. Herbaceous plants appear rarely to serve as host plants at this time, though single adults have been found on many, and nymphs on *Hoslundia* and *Indigofera*. This is the reverse of the position in the elephant-grass zone, where trees and shrubs seem to be much less important than herbaceous plants as means of survival of *Lygus* in the dry season.

In April and May a great change occurs in the ecology of *Lygus* in the countryside generally in consequence of the maturing of the grain crops, *Eleusine* and sorghum, both of which are major host plants of the insect when the grain is nearly ripe. An enormous population builds up rapidly by breeding in these two crops, and since they are grown in abundance everywhere all other host plants become negligible by comparison at this time as sources of the insects. There is very little tendency for *Lygus* to spread from the grain fields so long as the grain is left undisturbed, and any cotton which may be sown abnormally early (April or earlier) remains unattacked throughout this period.

There is little check on the multiplication of *Lygus*. The two parasites that occur at Kawanda both attack *Lygus* in the grain crops at Serere, but the percentage parasitism remains exceedingly low for reasons explained elsewhere. Certain other Capsids, notably *Stenotus* on certain flowering grasses and *Lygus* Sp. D on composites, are heavily attacked by these two parasites, as at Kawanda, but since *L. simonyi* is not present on the host plants of these other Capsids and its own wild host plants are scattered and uncommon by comparison, parasitism has an almost negligible effect on the population as a whole.

The grain crops are harvested in June and July, the *Eleusine* rather earlier than the sorghum. Quite suddenly, therefore, the *Lygus* population is deprived of its principal food supply and mass migration takes place in all directions from every grain plot. The earlier migrants arrive in the May-sown (and earlier sown) cotton plots in large numbers in or about mid-June, and mass dispersal from the grain plots continues until harvesting is completed and results in the accumulation in a few weeks of a large population in every cotton plot. Breeding in cotton begins at once, but for the first three weeks or so the damage is largely due to the wandering adults. Later, nymphs are abundant and do even more damage than adults. In the second half of July every plant is damaged and the terminals of many branches are already dying.

Thus the sudden invasion of cotton by vast numbers of *Lygus* which occurs in the type of country represented by Serere contrasts very strikingly with the gradual infiltration process which takes place in the elephant-grass zone over a period of many weeks.

The suggestion that the grain crops are the principal source of *Lygus* on cotton was first put forward by Hancock (1935). Gwynn devoted much attention to this aspect of the problem and proved beyond doubt that Hancock's suggestion was correct. In the course of a full discussion of his evidence he remarks : " it is unnecessary to postulate any other source to account for the large scale invasion of early cotton by the bug which takes place at this time ".

The June and July sowings at Serere are less attacked than the earlier sowings, since both escape the main onslaught from the grain crops. Nevertheless, both are very severely damaged as compared with the corresponding sowings at Kawanda.

Breeding continues in all sowings throughout July, August and September. Gwynn's observations indicate that the May-sown cotton commences to become unsuitable for the breeding of *Lygus* at the end of August, and the other sowings correspondingly later. If, however, all the sowings in any given area are considered together, there is no marked decline in *Lygus* until October, by which time all the plants have reached a state of maturity in which succulent tissues suitable for the insect are absent.

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* All reared to adults for determination.

By mid-October nymphs are usually very scarce and the outbreak has finished. In this connection it must be remembered that owing to the difference in climate the plants mature more rapidly at Serere than at Kawanda. In spite of this, the outbreak continues in severe form much longer at Serere.

The parasites that attack *L. simonyi* do not follow it into the cotton fields at Serere at the time of the initial invasion, nor do they attack it in cotton, subsequently. The contrast with Kawanda is as great as it well could be. Since the *Lygus* population at Serere is derived almost entirely from grain crops in which parasitism is very low, it is not surprising that the harvesting of grain does not result in the general spread of parasites ; and the suddenness and extent of the migration from grain would in any case result in the temporary escape from parasites of a high proportion of the *Lygus* population. But these facts do not explain why the two parasites do not steadily spread into cotton from other sources and multiply in it. That they do not is certain, since I have dissected many samples of nymphs of *Lygus* from cotton in two successive years and have very rarely found any parasitised. Yet they are abundant in *Stenotus* on grasses and *Lygus* Sp. D on composites throughout the time during which *L. simonyi* breeds on cotton, and these two other Capsids and their food plants are common (as at Kawanda) near almost all cotton plots in the drier areas. The explanation may lie in the existence of different biological or ecological races of parasites in different types of country, since it is known that different races of certain other parasites, in searching for hosts, frequent different plants or different types of vegetation. At Serere (and also in Buruli, and therefore presumably throughout the drier areas) the two species of *Euphorus*, of which *L. simonyi* is one of the principal hosts at Kawanda, are mainly parasites of *Stenotus* and *Lygus* Sp. D.

The failure of the parasites to attack *L. simonyi* in cotton at Serere results in the maintenance of a high population by breeding for several months. This population may be supplemented to a slight extent by immigrants from scattered wild host plants, as at Kawanda, but the additional immigration is certainly almost negligible compared not only with the initial influx from grain but also with the cumulative result of breeding. At Kawanda, the dispersal of adults from scattered alternative host plants is the only source of *Lygus* except in July, since the parasites do not permit nymphs on cotton to become adult after the end of that month.

Possible Means of reducing Damage.

A. BOTANICAL POSSIBILITIES.

1. *Resistant Varieties.* It may now be regarded as definitely proved that some of the varieties of cotton grown in Uganda are consistently more susceptible to leaf damage by *Lygus* than others. In view of the obvious differences which exist in characters such as rate of development, habit, colour, hairiness, succulence, and so on, it would be surprising if this were not the case. Nevertheless, all varieties are very badly damaged, and we are still in the stage in which we must speak in terms of susceptibility rather than resistance. We have no resistant variety.

(*a*) *Prospects.* In these circumstances it is well to review the position and prospects. Gwynn, writing on the possibilities of control, expressed the view that " perhaps the most hopeful line of attack is further investigation into the possibilities of varietal resistance ". Stephenson wrote : " The development of resistant varieties is fairly promising, but whether resistance to *Lygus* can be combined with all the other desirable characters necessary in cotton remains to be seen. . . . The degree of resistance so far obtained is small but I see no reason why this could not be raised." My own view, based more upon an intimate acquaintance with the insect itself than on consideration of the possibility of increasing existing differences by plant breeding, is that the prospects of obtaining a resistant variety are not good, but that two characters, " toughness " of tissues and hairiness, are undoubtedly associated with resistance and are sufficiently promising to warrant special study. I shall deal with these two characters hereafter under separate headings.

So far as *Lygus* is concerned, we have reached the stage in cotton breeding work beyond which we can make no progress unless we decide more definitely what we are breeding for. The analysis of the data obtained by leaf-damage counts in variety trials and other large-scale experiments has shown us that slight differences exist. To have proved this is a most important step forward, but we must be careful not to continue merely to demonstrate that differences exist. We must try to ascertain precisely wherein they lie, and to this end it is necessary to study throughout their development certain individual plants having characters believed to be associated with resistance, and also to study the insect itself in all stages in association with those characters. I do not for one moment suggest that observations on variety trials can no longer tell us anything useful concerning *Lygus* ; on the contrary, I think it essential that such observations should continue, but they must be supplemented concurrently by detailed observations, planned for this purpose, in the field and the laboratory.

I have already referred to tests of nymphs of *L. simonyi* on many forms of cotton and on other plants. All these tests were done in humid conditions in the laboratory and with abnormally large populations of nymphs. My immediate object was to ascertain whether all cottons react in the same way if *Lygus* can be induced to attack them. There was no reason to assume that all those attacked in these special conditions would also be attacked similarly in the field, but this was beside the point in any case. The cottons tested included forms and crosses of the following species :—*G. hirsutum*, *G. barbadense*, *G. purpurascens*, *G. darwinii*, *G. taitense*, *G. trilobum*, and *G. arboreum*. Wherever possible both glabrous and hairy plants were tested. In every case, without exception, a strong reaction (blackish spots) was apparent in a few hours, and an equally strong reaction resulted in plants of other genera. There were differences in the time taken for the spots to develop (2 5 hours), but in all cases the damage was very severe. From this I conclude that there is little possibility of obtaining a cotton whose tissues can resist the mechanical or toxic action that results from insertion of the stylets, and that our best chance of obtaining resistance lies in some physical character, of a nature or degree so different from anything we have at present as to be almost revolutionary, which will actually prevent insertion, or hinder oviposition or the activities of very small nymphs.

Consideration of the alternative host plants lends further support to this conclusion. An insect with so wide a range of host plants as *L. simonyi* can scarcely be expected to discriminate to any great extent between different varieties of any one of them. A variety of cotton which is resistant on account of lack of attractiveness or palatability is out of the question. If the death of the tissues which results from the attack of the insect could be proved to be primarily due to toxic action, there would be slightly more hope of obtaining a resistant variety, since resistance to the toxin rather than the insect would suffice. But in this case also the prospects seem poor, because plants of other genera, such as *Hibiscus*, *Abutilon*, and *Phaseolus*, react to the attack of the insect in the same way as cotton. It was thought at one time that cotton was not entirely suitable as a host plant for *Lygus*, mainly because the plants reach a stage, before they are mature, when breeding on them almost ceases. It was therefore felt that a slight change in the physiological make-up of the plant might tip the scales towards resistance. This view, however, is no longer tenable ; all the host plants of *L. simonyi* are suitable for it for only a short period, and cotton is no exception. In fact, I now regard cotton (notably *G. hirsutum* and its derivatives) as a plant particularly well suited to the requirements of the insect.

In 1939, Stephenson selected adjacent plants in pairs for their apparent susceptibility and resistance to attack as judged by leaf damage. The plants of each pair, which were as nearly alike as possible in other respects, were both damaged, but not equally. In the following season the progeny of the less damaged plants again showed less damage, thus indicating that degree of reaction to *Lygus* is hereditary.

This result, by itself, which was obtained in four different varieties, means that there are hereditary differences in degree of resistance between plants of one recognised variety as there are between varieties. It remains to be demonstrated whether the differences can be manipulated and increased by breeding, and wherein they lie. This is another instance of the necessity for watching and recording individual plants throughout their growth to supplement and explain conclusions drawn from general observations.

(*b*) *Leaf Texture.* This term is used for want of a better. Plants, varieties, and species of cotton differ in certain respects which may be vaguely referred to as " dryness " or " toughness " and " succulence ", " sappiness ", or " softness ", but the use of any of these terms at present is dangerous. It does not matter which of them we use provided that we recognise that the literal meaning of any of them may be erroneous as applied to resistance to *Lygus.*

We now have abundant evidence, from both laboratory and field observations, that a plant of which the leaves are dark in colour, rather small, and harsh to the touch, is less damaged than one with light green, large, soft leaves. The terminals of the former can be made as susceptible as those of the latter by placing their stems in water and exposing them to high humidity, but in normal field conditions in which the humidity is rarely very high for long, they are less susceptible. Moreover, while " toughness " in this sense may be due merely to weather or age of plant or soil conditions, it is also inherent to some extent in certain varieties and species. That is to say, in any given set of conditions varieties differ in " toughness ", and different sets of conditions cause differences in this respect between plants of any one variety. But it does not follow that the same fundamental factor is responsible for differences between varieties and between plants of one variety. It is possible that the difference between plants is directly due to water supply only, while that between varieties and species is due to some factor, such as toughness of epidermis or cell walls, which may be largely independent of water supply.

Whatever the fundamental factors may be, the result is the same so far as *Lygus* is concerned. The insect does not, and probably cannot, insert its stylets far into the tissues of a " tough " plant or variety except in an abnormally humid atmosphere. But when it does insert them the usual reaction occurs.

Any ground treatment, such as manuring, mulching, or deep cultivation, which increases the " succulence " of a plant and its capacity for rapid growth also increases susceptibility to leaf damage by *Lygus.* It has been suggested that nitrogen is responsible for this in some treatments, but I agree with Stephenson that " a far more likely theory is that water supply is the factor concerned ".

It is essential, for the time being, to guard against the assumption that a " sappy " or " succulent " plant is undesirable merely because its leaves show more damage. Yield is the ultimate test, and it is known that large " succulent " plants frequently yield more than smaller, " tougher " types in spite of *Lygus* damage. " Succulence " and rapid growth go together, and it may be that when the plants are young each leaf bud and flower bud is in a condition suitable for *Lygus* for a shorter period on rapidly-growing plants ; or that the suitability of the leaf buds as food causes the insects, especially nymphs, to wander over the plant less than they otherwise would and therefore to attack a smaller proportion of flower buds and terminals. It is also possible that rapidly-growing plants are better able to recover when very young from the initial onslaught of *Lygus.* Whatever the reason, a capacity for rapid growth gives a degree of resistance, and we are faced with the unfortunate fact that both " toughness " and " succulence " are associated with resistance, the intermediate condition (*i.e.* the usual condition in Uganda) being the most susceptible as judged by crop damage. But whereas a " tough " type of plant might be expected to give almost complete resistance, a " succulent " plant will always be damaged. The choice between the two depends on whether the former type has any other advantages, and the solution of the problem must obviously be left mainly to the plant breeder and the physiologist.

(*c*) *Hairiness.*—In 1943 I began work on hairiness of cotton plants as a possible means of providing resistance. This preliminary study was designed partly to test various methods of comparing hairiness in different varieties and partly to decide upon a more extensive investigation in 1944. I am recording my observations as far as they have gone in the hope that they may help subsequent workers in this field.

I was greatly helped and stimulated in this line of enquiry by discussions with Mr. Parnell of Barberton. He and his staff have shown that certain types of hairiness give complete resistance to Jassids, and have devised a method for determining the nature of hairiness (Parnell & MacDonald, 1943). The method which I have used is a modification of theirs, and is somewhat simpler, but if further work in Uganda indicates that hairiness may be utilised as a factor providing resistance to *Lygus*, it may be desirable to adopt their method exactly. Meanwhile the simpler procedure is recommended because the work is, in any case, extremely trying and tedious.

It would be quite wrong to assume at the outset that because hairiness provides resistance to Jassids it can also give resistance to *Lygus*. There is so far little evidence for this. Moreover, the habits of Jassids and *Lygus* are different in many respects, and the hairiest cotton which we have in Uganda, M.U.8A, is badly damaged by *Lygus* although it has shown complete resistance to Jassids at Barberton. All our *G. hirsutum* derivatives, though varying considerably in hairiness, are highly susceptible to *Lygus*. Nevertheless, and in spite of these unfortunate facts, I can visualise two types of hairiness (the production of which by breeding is not, I think, impossible), which might give us a valuable degree of resistance, and for this reason I urge that studies on these lines should be continued.

The term " hairiness " covers a multitude of possibilities and combinations. There are long hairs and short ones, curly and straight ones, erect and recumbent ones, simple and compound ones, rigid and pliable ones. There are great variations in density and in the proportion of short and long hairs. There are almost completely glabrous varieties. And the effect of any particular type of hairiness may be quite different on adults and nymphs, especially very young nymphs. We could obtain complete resistance by a type of hairiness which could prevent adults from feeding and ovipositing, and damage could be greatly reduced by hairs which could hinder the movement of adults and nymphs, or nymphs only. Since very great damage is done in the drier areas of Uganda by the initial migration of adults from grain crops, although the subsequent damage by nymphs is even greater, it will be wise to aim in the first instance at the prevention of feeding and ovipositing by adults. A covering of very dense, short hairs (e.g. *G. tomentosum*) does not hinder adults in the least ; but there are indications that they are adversely affected by very long, erect, hairs, though in none of the cottons at present available in Uganda are the " long " hairs long enough or dense enough to give protection.

I doubt whether complete protection from adults is within the bounds of possibility. *Lygus* feeds principally on the young terminal buds and on young squares. The hairs on leaves and squares are much shorter (in the varieties with which I am familiar) than those on stems and petioles, and it seems unlikely that the length of hairs on leaves and squares could ever be increased sufficiently to give resistance to the attack of adults. On the other hand, the leaf and flower buds are very small and if the activities of the insect were restricted to them in consequence of greater hairiness on the stems and petioles, it is probable that it would not favour cotton as a host plant to anything like the present extent. Moreover, since the eggs are laid (so far as we know) mainly in the petioles of very young leaves, the hairiness of the petioles is of paramount importance. On these petioles (as on all other very young parts of the plant) the hairs are densely packed together, and they are not widely separated by growth until after the time when the petioles and leaves become unsuitable for *Lygus*. Thus, even on cottons which are only moderately hairy, the hairs are dense on the parts mainly frequented by *Lygus*. For these reasons I conclude that a study of hairiness should be based mainly on the petioles, and that density is of less importance than length where adults are concerned.

My studies of hairiness in this connection have not been confined to the hairs themselves. I have watched *Lygus* adults, under the microscope, feeding and ovipositing amongst the hairs of some of our hairiest plants, and I have measured the length of the rostrum and of the tibiae and tarsi of the legs of adults for comparison with the lengths of erect hairs. The insects have no difficulty in feeding or ovipositing in the young petioles of any of our cottons because the combined length of the tibiae and tarsi enables them to get sufficient grip near the bases of the hairs. It is clear that a hair length much greater than has yet been attained is required, and I am almost certain that a length of not less than 3 mm. on the petioles is necessary if any appreciable resistance against adults is to be obtained. Also, if a plant on which most of the " long " hairs on the petioles attain a length of 3 mm. is found not to be resistant, then the attempt to obtain resistance to adults can probably be dismissed as useless.

To hinder or prevent the activities of young nymphs a very different type of hairiness is required. The newly hatched nymph is exceedingly small and on leaving the egg, which is sunk in the tissues, it finds itself on the surface of the plant with the bases of hairs all round it. But even on the hairiest of our *G. hirsutum* derivatives it can move amongst the hairs with complete freedom. The density is not nearly sufficient to hinder it. Its environment is comparable to that of a man in a pine forest without undergrowth. Increasing the length of the hairs or trees does not hinder movement. If, however, a dense undergrowth can be added, movement becomes almost impossible. In the case of the very young nymph, a pubescent or tomentose covering (*i.e.* very short hairs with high density) would greatly restrict movement on the surface of the plant, and would probably prevent the nymph from feeding from the " surface " of the tomentum if the thickness of the latter (not necessarily the actual hair length) were about 0·5 mm.

General field tests of cottons having different types of hairiness are essential, but are unlikely to solve the problem by themselves. They must be supplemented by direct observation of both adults and newly hatched nymphs on the terminals in the laboratory. It was my intention to arrange for a plentiful supply of newly hatched nymphs (in itself a matter of some difficulty) for experimentation on *G. tomentosum* and *G. mustelinum* in particular.

If it is found that only partial resistance to both nymphs and adults can be obtained, by different types of hairiness, it would be worth while considering the possibility of combining the long hairs of one of the *G. hirsutum* derivatives with the short, dense hairs of *G. tomentosum* or *G. mustelinum*. This might double the degree of resistance to *Lygus*.

The method that I adopted for studying the hairs themselves consisted in placing a millimetre square, made of crossed human hairs, on the leaf, or on the edge of a cross-section of leaf or petiole, and drawing all the hairs within the square and projecting beyond it. The leaf selected was the first fully-developed one from the top of the plant, on the main stem. (The fact that a leaf of this age is not attacked by *Lygus* is immaterial.) Drawings were made of surface views at several places on the under surface of the leaf, views of narrow strips, placed on their edges, cut from various places on the leaf (avoiding main veins), and edge views of transverse sections of the petiole cut at distances of 5 and 10 mm. from the leaf lamina. In order to standardise the width of the strips and the thickness of sections, two safety razor blades separated by a selected glass microscope slide were employed for the sake of simplicity and rapidity. This gave a width of strip and thickness of section of 0·96 mm., and was found suitable for all cottons examined, but greater hair density would necessitate using the blades closer together. So far as *Lygus* is concerned, it is, I think, unnecessary to measure the total density of hairs. A visual impression is enough. But length must be measured. The mean length of all hairs is unimportant, and it is sufficient (and also necessary) to know the density of hairs exceeding 2·5 and 3·0 mm. in length.

My investigation, which included the examination of a large number of sections besides those actually drawn, led me to conclude that for routine examination of a large number of plants the petiole hairs alone will suffice. This greatly reduces the work. A few leaves should always be examined, but only to ascertain whether the leaf hairs are in any way abnormal. I do not mean that the leaf hairs have no bearing on the problem, but that the petiole hairs are sufficiently indicative of the hairiness of the plant, at least in *G. hirsutum*.

For varieties with long hairs, I was proposing to obtain pictures of the petiole hairs by direct photographic prints in order to facilitate the work further. Also it was suggested to me that silhouette photographs of petiole hairs could be obtained by means of an enlarger. I did not try either of these methods, but both would have the great advantage that a large number of sections could be dealt with at the same time.

The preliminary investigation served to show what types of hairiness do *not* give us appreciable resistance. This negative evidence is valuable as a guide. The variety M.U.8.A, which was sent from Tanganyika because it showed some indications of resistance to *Lygus* there and because it is considered very hairy, was very severely damaged by both adults and nymphs in Uganda, though the damage was perhaps slightly less than that on our other *G. hirsutum* varieties. The same applies to O.S.P.16, another variety reputed to be very hairy. (I use the term " hairy " here mainly with reference to length of hairs.) These two varieties proved in Uganda to be only slightly more hairy than B.P.52, a variety which has been in general cultivation for some years and is known to be highly susceptible to damage. On the petiole of M.U.8.A many hairs exceed 1·0 mm., few attain 1·5 mm., and the longest are 2·0 mm. O.S.P.16 is similar, except that the hairs are rather shorter. B.181, grown in bulk at Kawanda in 1943, has shorter and denser hairs than either M.U.8.A or O.S.P.16, most of the hairs being under 1 mm. in length. It is highly susceptible. B.P.50.R, which has given some indication in damage counts of a degree of resistance, though not consistently, has fairly long hairs, some of which approach 2·0 mm., but the density is low.

It is now clear that the differences between the varieties that I have mentioned are not such as to give extensive differences in resistance ; and that M.U.8.A, which is more hairy as regards length (though only slightly so) than any other cotton in Uganda, has little advantage over other cottons in this respect. It should, however, be noted that, judging from the drawing in the recent paper by Parnell and MacDonald (1943), M.U.8 (= M.U.8.A) at Barberton has much longer petiole hairs (3 mm. being frequent) than M.U.8.A in Uganda. The extra millimetre might make all the difference. The hairiness of M.U.8.A gives it a high degree of resistance to Jassids in Uganda, though not to *Lygus*, and it may be that the crucial hair length for *Lygus* is 3 mm., as I have already suggested.

The growth of hairs, particularly as regards length, is almost certainly affected by numerous environmental factors. It is quite possible that the length of the hairs of M.U.8.A is less in Uganda than elsewhere. It is also possible that there are variations from season to season in every variety, depending mainly on the rate of growth of the plants. It may be necessary, therefore, if future work encourages the belief that hairiness can provide resistance, to aim at obtaining a margin of safety in hair length.

An isolated observation, but one nevertheless of possible value, concerns a single plant in a row of B.C.81 (Tanguis × B.P.52) grown at Kawanda in 1943. This plant had more crop and showed much more extensive growth in most of its branches than almost all its neighbours, and the number of nodes on branches is an inverse measure of *Lygus* damage. Examination of the petiole hairs showed not only a high proportion of hairs approaching 2·0 mm. in length but also a tendency for the hairs to intertwine spirally which I have not seen in any other plant. The increased rigidity which resulted from the intertwining of 2, 3, and in some cases 4 hairs together was very striking. I cannot assert that this character provided resistance, but it is worth considering.

The leaf hairs (under surface) bear out the conclusions drawn from the petiole hairs. M.U.8.A, O.S.P.16, B.P.52, and the selected plant of B.C.81 are similar, all having numerous hairs of about 1 mm. though the mean length is much less, but the long hairs of M.U.8.A and of the selected B.C.81 plant are slightly longer than those of the other two. B.181 has very much shorter and denser hairs, while B.P.50.R is intermediate.

Finally, I must introduce a note of caution by remarking that there have been indications at both Kawanda and Serere that completely glabrous plants are less susceptible than moderately hairy ones. In the laboratory the glabrous plants were highly susceptible, but in the field they were less damaged than most others. It is possible, therefore, that moderate hairiness is the ideal condition for *Lygus*. This aspect of the problem deserves further investigation.

2. *Type of Branching*.—Any means of delaying the production of the first flower buds (squares) would reduce loss of crop. At Kawanda, most of the damage is done on the earliest (May) sowing and there is a marked decline in damage after the end of July. The first squares appear early in July. Delaying the production of squares by only two weeks would therefore reduce the period of the main attack on squares by half. At Serere, where the period during which severe damage is done is much longer, a delay of two or three weeks would not greatly affect the period of attack, but it would enable the earlier squares to avoid to a great extent the initial onslaught from the grain crops which is so characteristic of the areas which Serere represents.

The most obvious means of delaying the production of squares is by refraining from sowing so early. This I have dealt with elsewhere in this report. The other method is to grow a cotton on which most of the branches are monopodial, unlike most of our present varieties. Since monopodia begin to produce squares about 3 weeks later than sympodia, judging from my individual plant records, the percentage of squares attacked would probably be much lower on a variety of mainly monopodial habit.

Monopodia have another great advantage over sympodia. The terminals of monopodia and the terminal of the main stem are comparatively rarely destroyed by *Lygus*. The terminals of sympodia, on the other hand, are usually destroyed by *Lygus* at an early stage of growth of the branches. Consequently, each monopodium and the main stem produce many nodes, while each sympodium produces very few (rarely more than 4 and frequently only 2 in the May sowings). I strongly suspect that the main reason for this is that the terminal bud of a monopodium, like that of the main stem, is protected by young developing sympodia, which not only afford direct protection but also reduce the chances of attack on the apical bud itself. Further, a monopodium, like the main stem, has branches throughout its length, each with its own terminal bud, while a sympodium has no branches ; consequently, a nymph on a monopodium has ample choice of terminal buds while one on a sympodium has no choice.

B. BIOLOGICAL CONTROLS. I have already given an account of the general biology of the two* important parasites of *L. simonyi* and of their economic status in outbreaks at Serere and Kawanda. It remains to consider whether their usefulness can be increased in any way and whether it is worth while to attempt to supplement their activities by means of other parasites which may exist elsewhere.

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* After a preliminary examination of specimens of these parasites, Mr. Nixon has expressed the opinion that one of them (T.801A) may include two very closely related species. If this view is confirmed; future work should include further investigation of host preferences and suitable modification of the plans suggested here for testing at Serere the parasites from Kawanda.

It is obvious that if we could do anything to induce the parasites (*Euphorus* spp.) to frequent cotton at Serere (and in the drier areas generally) as they do annually at Kawanda we should very greatly reduce the damage done by *Lygus*. It is imperative in my opinion that the suggestion that different biological or ecological races of *Euphorus* exist in different areas should be followed up by an attempt to establish both species from Kawanda at Serere. I am not optimistic of the result, but there is a chance of success, and since the attempt would not involve more than a few months of work (which cannot be said of any other possible method of reducing damage) and would have the advantage, whatever the result might be, of narrowing the field of future work, it should be made as soon as possible and given preference over other lines of investigation.

There is little prospect of increasing the usefulness of the parasites by agricultural methods. Interplanting does not help. But the importance of the proximity of elephant-grass and certain other grasses and other plants as sources of alternative hosts of the parasites should not be overlooked, and plot size is important in the same connection. Elephant-grass is a source of *Euphorus* spp. not only through its own Capsid fauna but also because it shelters many plants which are attacked by various Capsids, including *L. simonyi*. Any procedure which facilitates the entry of the parasites into cotton plots, and their distribution through the plots at an early date, is to be recommended from this point of view, and a series of long narrow strips separated by elephant-grass, or a number of small scattered plots, is preferable to one large plot of the same area. There are, however, many other considerations to be taken into account in deciding plot size and shape.

In one part of Uganda (Madi and neighbouring areas—*see* page 146), in the southern Sudan, in parts of Tanganyika, and at Barberton, and no doubt in many other places, *L. simonyi* does little or no damage to cotton although it is probably present. There are many factors besides parasites, notably climate, distribution of alternative host plants, and time of harvesting grain crops, which may account for this, but the fact remains that our lack of knowledge concerning the activities of parasites in these areas is a weak point in our investigation. A beginning should be made in Madi, especially on the Nile flats, for although my own work led to the conclusion that the grain crops there act as trap crops, later developments have made me wonder whether a parasite may not also be concerned. The southern Sudan and parts of Tanganyika should also be visited to ascertain the reasons for the scarcity of *Lygus*. I should strongly favour the introduction into Uganda of any parasite found attacking *L. simonyi* on cotton elsewhere, and it may not be out of place to remark here that certain other African countries that suffer from *Lygus* might derive benefit by the introduction of parasites from Uganda, especially in areas where cotton is a recent introduction and which are isolated by natural barriers.

In any field investigation of the parasites of *L. simonyi*, it is necessary to pay attention to various host plants, particularly sorghum, in addition to cotton. The important and curious fact that parasitism in sorghum is consistently low as compared with that in cotton, even where the two crops are growing in adjacent plots, suggests that a parasite better adapted to find the *Lygus* nymphs in sorghum heads than are our two species of *Euphorus* is urgently required. Alternatively, assuming (as I do) that the reason for the failure of *Euphorus* to be effective in sorghum is that it cannot often reach the nymphs amongst the massed seeds, the degree of parasitism could be increased by growing a variety having more open heads. At Kawanda in September, 1943, when parasitism in cotton was 98 per cent. and in *Pseudarthria* 80 per cent., in open heads of sorghum it was 20 per cent. and in closed heads only 2 per cent. Since the " open-headed " and " closed-headed " sorghums were mixed and the latter predominated, it is likely that the difference in percentages would be considerably greater if the two types of sorghum were grown in separate plots. It is noteworthy that Stephenson remarked : " The open head types of sorghum only harbour half the *Lygus* population of the compact types ". This was at Serere, and it is not known whether the difference was due to parasites, but whatever the cause it appears that growing "open-headed" types in the countryside generally might greatly alter the *Lygus* population on cotton. This point certainly warrants further investigation, if the open types are not considered undesirable on other grounds.

C. AGRICULTURAL PRACTICE. All investigators of *Lygus* in Uganda have considered various changes in agricultural practice as possible means of avoiding damage. Most of these can be dismissed as impracticable or ineffective, but two possibilities warrant consideration because they are closely connected with the amount of damage done by *Lygus* as well as the general agricultural policy and customs of ny acotton-growing area. These are the sowing date of cotton and the possibility of using millets as trap crops.

1. *Sowing Date of Cotton.*—The time of planting of food crops has been determined by generations of African experience. The sowing date of cotton is based mainly on European advice after comparatively few years of experience, and it is not yet certain that the present custom is the best in all districts.

Sowing usually begins in May, but most plots are sown later. In the elephant-grass zone much of the damage would be avoided if sowing began in June instead of May. Elsewhere, the damage to the June and July sowings would still be severe, but it might be considerably less than at present because there would be no cotton during the first half of the period of migration of *Lygus* from the grain crops and because the large population which is built up by breeding in the May sowings, and which undoubtedly spreads to the later sowings to a considerable extent, would be absent. The fact that in the drier areas the grain crops are the principal source of *Lygus* raises the obvious question as to why cotton is planted at a time such that the plants are in an ideal condition for *Lygus* when the migration from grain takes place.

In some districts it would be possible not merely to delay sowing for a month or so, but to sow in a different season of the year, utilising the second rains instead of the first. It is almost certain that cotton sown towards the end of the year in the type of country represented by Kawanda would almost completely escape *Lygus* damage, partly owing to the cumulative effect of parasitism from May onwards and partly to the condition of many wild plants which are still suitable as food for *Lygus* in October and November. Gwynn, writing of Serere, remarks : "The comparative freedom from serious *Lygus* damage of cotton sown in the second rains is a fact which has frequently been noted. The chief exception to this is when late-sown cotton is planted among early cotton ; . . . The only adequate explanation seems to be the absence at this time of any large migratory population comparable to that present in June and July ". It is unlikely that the planting of cotton in the second rains will ever be considered feasible in the hotter districts, but in parts of the elephant-grass zone it may be.

It would be foolish to recommend any drastic change in the time of sowing on account of *Lygus* only, serious though it is. So many other factors are involved, not the least of which is the probability that if *Lygus* could be controlled by other means the May and June sowings would give the best yields. My point is that in any future consideration of a change in sowing date *Lygus* must be one of the determining factors.

2. *Grain Crops as Trap Crops.* In the north-west of Uganda there is a comparatively small area of country in which *Lygus* does little damage and locally none whatever. The southern boundary of this area is a line passing between Moyo and Rumogi, Zaipi and Attiak, and extending eastwards slightly north of Kitgum. Since *Lygus* has not been recorded as a pest of cotton in the Sudan, it is possible that this small area in Uganda is actually only the southern extremity of a vast expanse of country in which *Lygus* damage to cotton is slight.

The same small area of Uganda is also characterised by a pronounced difference in the customs of the people as regards grain crops. This has no doubt evolved in the course of time in consequence of climatic differences. South of the imaginary line the sorghum has already been harvested at the time when the cotton is susceptible to *Lygus* attack. North of the line there is at this time an abundance of maturing sorghum in a condition ideal for *Lygus*. It is customary north of the line to obtain two crops of sorghum per year, the first by sowing and the second by ratooning, and ratooning produces a succession of flowers and grain during the time when the cotton is young. *L. simonyi* is abundant in sorghum heads throughout the area at the critical time, but it does not spread to cotton. The sorghum continues to be an entirely suitable host plant and *Lygus* has no occasion to leave it. Whether a similar state of affairs exists in the case of *Eleusine* is uncertain.

There is no doubt whatever that sorghum acts as a trap crop in this area, though not planted as such. Whether it is the main factor in the prevention of *Lygus* damage on cotton is another matter, but I believe that it is. In any case, since harvesting of ratooned sorghum proceeds over a long period there is no sudden exodus of *Lygus* as there is in some other districts. The cutting of a few ripe heads in a plot merely tends to drive most of the *Lygus* to other heads in the same plot, not to cotton plots nearby. The lack of a sudden migration accounts by itself for less damage in this area than elsewhere, but only the complete lack of any tendency to spread from grain could account for the complete absence of *Lygus* on cotton in certain areas, notably in small plots on the Nile flats, unless some other and wholly undetected factor is at work. It is possible that natural enemies are an important factor also.

In an experiment at Kawanda in 1943, a series of successive sowings of sorghum was grown alongside a similar series of sowings of cotton, the sowing dates being arranged so that at least one of the plots of sorghum was in a condition suitable for *Lygus* at all times during the period when the cotton was itself susceptible. The sorghum heads continuously supported a large population of *L. simonyi* and parasitism in the sorghum was low, as always. Despite the constant presence of this large reservoir of *Lygus*, the cotton was not attacked more severely in this experiment than elsewhere at Kawanda. This, though not conclusive, is highly suggestive. Since the normal annual infestation on cotton at Kawanda is derived from a great variety of mainly wild plants and not to any considerable extent from grain crops, plots of sorghum cannot prevent the usual population from reaching cotton. But in areas where grain crops are a predominant feature of the countryside and are the principal source of the infestation on cotton, the *Lygus* population on cotton would be greatly reduced if the grain crops were harvested gradually over a long period or were ratooned.

I am satisfied that any change in policy which would ensure the harvesting of grain crops at a different time of year or over a long period would very greatly reduce *Lygus* damage on cotton in all the districts which at present suffer most severely. But the difficulties in the way of any such change are very great, if not insuperable, since all food crops are of paramount importance to the peasants and their customs in regard to them are based on experience and are therefore usually sound. Consequently, the possibility of utilising grain crops as a means of controlling *Lygus* on cotton falls into the same category as a change in the sowing date of cotton made for the same purpose. The importance of both possibilities lies in the necessity for considering their bearing on the *Lygus* position whenever any general change in agricultural policy may be contemplated.

References.

HANCOCK, G. L. R. (1935). Notes on *Lygus simonyi,* Reut. (Capsidae), a Cotton Pest in Uganda.—Bull. ent. Res., **26**, p. 429.

HARGREAVES, H. (1940). Accounts of Cotton and other Pests.—*Agriculture in Uganda,* edited by Tothill, J. D.

McGREGOR, E. A. (1927). *Lygus elisus* : A Pest of the Cotton Regions of Arizona and California.—Tech. Bull. U.S. Dep. Agric., no. 4.

MUESEBECK, C. F. W. (1923). A Revision of the North American Species of Ichneumon-Flies belonging to the Genus *Meteorus* Haliday.—Proc. U.S. nat. Mus., **63**, art. 2.

——. (1936). The Genera of parasitic Wasps of the Braconid Subfamily Euphorinae, with a Review of the Nearctic Species.—Misc. Publ. U.S. Dep. Agric., no. 241.

PARNELL, F. R. & MACDONALD, D. (1943). Empire Cotton Growing Corporation. Progress Reports from Experiment Stations 1941–42. London, 1943.

PETHERBRIDGE, F. R. & THORPE, W. H. (1928). The common Green Capsid Bug (*Lygus pabulinus*).—Ann. appl. Biol., **15**, p. 446.

POPPIUS, B. (1912). Die Miriden der Aethiopischen Region. Helsingfors.

THE TOXICITY OF DDT TO THE HOUSEFLY, *MUSCA DOMESTICA*, L.

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Introduction.

For some years before the present war, the pyrethrins were the chief toxic constituents of sprays for the control of flies and mosquitos, but the shortage of pyrethrins during the war has led to intensive research to discover ways of utilising the available supplies to the utmost advantage. Two main lines have been followed, (i) to discover substitutes for part or all of the pyrethrins in a spray, and (ii) to discover synergists, particularly those classed as activators, *i.e.* substances, themselves practically non-toxic, which will markedly increase the toxicity of the pyrethrins. Pursuit of the former line has led to widespread and intensive investigation of the remarkable lethal action on certain species of medically important insects of the synthetic organic chemical *p,p'*-dichlordiphenyl-trichlormethyl-methane*, now known as DDT. A most interesting account of the years of work leading up to the discovery of DDT as an insecticide has been given by Läuger, Martin and Müller (1944).

In the United Kingdom, experimental work on the control of insects and mites of medical importance, especially to the Fighting Services, has been co-ordinated by an Insecticide Development Panel set up by the Ministry of Production for this purpose. As part of this general investigation, and at the request of the Department of Hygiene, War Office, the Pest Infestation Laboratory undertook an investigation into means of economising pyrethrum in fly sprays, including assessment of the value of DDT for incorporation in such sprays. The results now given in this report were communicated to the Insecticide Development Panel from time to time during 1943–44.

Insecticides.

Five samples of DDT have been used in this investigation. The sample generally employed is referred to as TA.29, and was a Swiss commercial product containing 74·6 per cent. of the pure compound ; the other samples are described in the body of the paper. Unless otherwise stated, the abbreviation " DDT " is used for the impure products and the concentrations of DDT in insecticides are stated in terms of these products and not of the pure chemical.

When pyrethrins were mixed with DDT, a concentrate (TA.21) was used, containing 4·80 per cent. w/v total pyrethrins in Pool burning oil. The Pool burning oil, used as the solvent in preparing the sprays, was the British war-time grade of kerosene.

As standards for assessing the relative toxicity of solutions containing DDT, two preparations were employed—(i) Official Test Insecticide (O.T.I.) as supplied by the National Association of Insecticide and Disinfectant Manufacturers, New York, and containing 0·1 per cent. w/v total pyrethrins in a refined odourless kerosene, and (ii) a fly spray supplied for Service use containing, nominally, 0·1 per cent. w/v total pyrethrins in Pool burning oil ; this will be referred to as " Standard Fly Spray ".

Insects.

The test insects were adult houseflies, *Musca domestica*, L., reared on an artificial diet at 27·5° C. and 60 per cent. R.H. The flies were fed on a 1 : 1 mixture of milk and water and were 4–6 days old when used.

Experimental Technique.

Tests were carried out in a small fly spray chamber, in rooms and in huts.

The test chamber was a glass-fronted wooden box, 3 ft. by 3 ft. by 2 ft., into which the insecticide was atomised by means of an Aerograph artist's brush Type *AE*, using the coarsest setting of the no. 2 nozzle at an air pressure of 50 cm. free mercury. Before each spraying the interior of the chamber was thoroughly swabbed with a 10 : 1 mixture of industrial methylated spirit and acetone and a clean sheet of absorbent paper was laid on the floor. The chamber was housed in a room maintained at 27·5° C. and 60 per cent. R.H. A batch of flies was liberated into the chamber before spraying and exposed to the insecticidal mist for 10 mins. The residual mist was then removed by forced aeration and the percentage knock-down (ataxia) noted, after which the flies were counted and returned to their muslin cage for observation of the mortality 24 hours later. In tests in which the lethal effect of a spray was investigated, a dose of 2·5 ml. was atomised into the chamber, but, for assessment of the knock-down effect only, the dose was reduced to 0·4 ml. Normally, three to four replicates were used in each test, and it has been possible to draw conclusions of practical significance without recourse to detailed statistical methods, an advantage in view of the urgency of most of the work. A fuller account of the chamber and its use will be published later.

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* This name is used because it is specific, yet shows the origin of the abbreviation DDT.

The results of the chamber tests were checked by experiments on flies liberated in rooms or huts, in which the spray was atomised by hand or power sprayers (paint-gun type). The rooms were of similar construction but different volumes. The walls and ceilings were distempered plasterboard or distempered cement blocks and the floors concrete ; each room contained some furniture and fittings, such as tables, cupboards, laboratory benches, etc.

The huts are described in the accounts of the appropriate experiments.

Toxicity of DDT alone.

Preliminary chamber tests with 10 per cent. and 5 per cent. w/v DDT (TA.29) in Pool burning oil showed that the DDT was extremely toxic to houseflies. It had no

TABLE I.

Chamber Tests of the Toxicity to Houseflies of different Concentrations of DDT in Pool Burning Oil.

Insecticide	No. of flies	Estimated K–D per cent.	No. of flies caught	Kill per cent.
O.T.I.	97 100 96	100 100 100	97 100 96	39·2 34·0 37·5
P.b. oil	82 89 87	25 25 25	22 29 25	27·2 24·1 8·0
1·0 per cent. DDT	73 87 60 85	100 100 100 100	73 87 60 85	100 100 100 100
0·5 per cent. DDT	88 111 85	85 85 85	82 105 80	100 100 100
0·1 per cent. DDT	94 89 94	65 65 65	82 76 86	100 98·7 98·8
0·05 per cent. DDT	92 92 96	50 50 50	70 66 77	95·8 100 100
0·02 per cent. DDT	88	25	30	90·0
Control	82 86	— —	— —	0 0

reversible knock-down effect like that of pyrethrum, but the onset of symptoms eventually leading to death was so rapid at these concentrations that the insects were severely affected within the 10 mins. exposure period. All the flies were killed in less than 24 hours.

Tests were then undertaken to discover the effects of lower concentrations of the DDT, using a dose of 2·5 ml. of each solution. The percentage knock-down at the end of 10 mins. was estimated, then as many as possible of the flies were caught and kept for observation of the mortality 24 hours later. A test with the Pool burning oil alone was included to show that most of the insecticidal action was due to the DDT. The results of this series of tests are shown in Table I. In these and succeeding tests in which knock-down was less than 100 per cent., it was not always possible to catch all the flies and the observed mortalities are therefore expressed as percentages of the numbers of flies caught.

DDT at a concentration of 1 per cent. was greatly superior to the O.T.I. for kill in 24 hours, although both caused 100 per cent. knock-down within the 10 mins. exposure period. At lower concentrations, however, the knock-down effect of the DDT declined rapidly, whereas very high mortalities of the flies were recorded at all concentrations down to 0·05 per cent. The result with 0·02 per cent. DDT must be accepted with caution for it was not replicated and was based on the mortality of only 30 flies of the 88 used ; the remainder were too active to be caught by the method in use. The lethal effect of the sprays was clearly due to the presence of DDT and not to the action of the oil alone, the percentage kills with which are greatly magnified because of the poor knock-down and consequent difficulty in catching the treated flies.

In view of the excellent results with 1 per cent. DDT in Pool burning oil, this spray was tried on a larger scale. Twelve thousand flies were liberated in a hut of 8,400 cu. ft. capacity with distempered plasterboard ceiling and walls, wooden roof trusses and a concrete floor. Two hundred ml. (about 25 ml./1,000 cu. ft.) of insecticide were atomised through a Maney hand sprayer in 5 mins. The subsequent observations are shown in Table II.

TABLE II.

Hut Test of Toxicity to Houseflies of 1 per cent. DDT in Pool Burning Oil.

Time after spraying	Observations
5 mins.	10 per cent. knock-down.
10 mins.	80 per cent. knock-down.
30 mins.	98 per cent. knock-down.
1 hour	99·5 per cent. knock-down.
24 hours	99 per cent. dead ; 0·5 per cent. affected ; 0·5 per cent. normal.
30 hours	99·5 per cent. dead ; 0·5 per cent. normal.

These observations confirmed the conclusion from chamber tests that 1 per cent. DDT was a powerful insecticide for flies.

Pyrethrum-DDT Mixtures.

Experiments have been undertaken to ascertain whether the rapid knock-down action of pyrethrins could be combined with the lethal effect of DDT by mixing the two toxic agents. A set of chamber tests gave the data shown in Table III.

From these data it was concluded that the rapid knock-down action of pyrethrum could be combined with the lethal action of DDT in Pool burning oil. For a speed of knock-down equivalent to that of the O.T.I., a mixture of 0·02 per cent. pyrethrins

+ 0·5 per cent. DDT would probably be necessary. At a rate of dosage likely to be applied under practical conditions, however, an insecticide containing a minimum of 0·02 per cent. pyrethrins + 0·05 per cent. DDT should be satisfactory.

Table III.

Chamber Tests of the Toxicity to Houseflies of Mixtures of Pyrethrins and DDT in Pool Burning Oil.

Pyrns. per cent. w/v	DDT per cent. w/v	Dose ml.	No. of flies	K–D per cent.	No. of flies caught	Kill per cent.
0·1 (O.T.I.)	—	0·4	95	57·9	55	3·7
			90	55·6	50	2·0
0·02	0·1	0·4	72	47·2	44	40·8
			73	34·3	37	32·4
0·02	0·05	0·4	85	32·9	50	14·0
			88	35.2	50	14.0
		2·5	94	100	94	88·2
0·01	1·0	0·4	75	36·0	70	100
0·01	0·05	0·4	80	18·8	50	24·0
			90	18·9	50	28·0
		0·8	85	31·8	50	24·0
			75	34·7	50	18·0
		2·5	90	90·0	87	85·1
			90	96·7	90	91·1
0·01	0·02	2·5	82	92·7	79	38·0
			92	92·4	88	42·1
Control	—	—	90	—	—	0
	—	—	86	—	—	0

Additional chamber tests confirmed these results, but room tests with 0·02 per cent. pyrethrins + 0·05 per cent. DDT in Pool burning oil indicated that this combination was indeed minimal and trials were therefore made of a spray containing 0·03 per cent. pyrethrins + 0·1 per cent. DDT.

Tests of 0·03 per cent. Pyrethrins + 0·1 per cent. DDT.

Special tests were made of the spray containing 0·03 per cent. pyrethrins + 0·1 per cent. DDT to ensure its adequacy in comparison with the Standard Fly Spray. The results of a chamber test are set out in Table IV.

In this experiment, the pyrethrum-DDT spray proved less efficient than the Standard Fly Spray for knock-down but greatly superior for kill. With the 2·5 ml. dose, however, both insecticides caused 100 per cent. knock-down well within the 10 mins. exposure period.

The two sprays were then compared in a room test. Unfortunately, the nozzle of the Maney hand sprayer became partially blocked during atomisation of the pyrethrum-DDT mixture, so that some of this insecticide was wasted through faulty application. This accident may well account for the observed slow rate of knock-down during the first 30 mins. with the pyrethrum-DDT spray. After this slow start, however, the DDT mixture soon equalled the Standard Fly Spray in percentage of flies paralysed and eventually killed 99·5 per cent. of the flies in 24 hours compared with a kill of 55 per cent. by the Standard Fly Spray.

TABLE IV.

Chamber Test of Toxicity to Houseflies of 0·03 per cent. Pyrethrins + 0·1 per cent. DDT in Pool Burning Oil.

Insecticide	Knock-down in 10 mins. (Dose = 0·4 ml.)			Kill in 24 hours (Dose = 2·5 ml.)		
	No. of flies	K–D per cent.	Mean K–D per cent.	No. of flies	Kill per cent.	Mean kill per cent.
Standard fly spray ..	107	68·2		102	25·4	
	111	70·3		100	25·0	
	103	68·9		90	26·7	
	101	72·7	69·7	105	29·5	26·7
0·03 per cent. pyr. + 0·1 per cent. DDT.	96	28·1		96	100	
	98	36·7		98	100	
	97	40·2		106	100	
	90	37·8	35·7	91	100	100
Controls..	—	—	—	104	0	
	—	—	—	98	0	0

In order to attempt a better comparison under practical conditions than was achieved in the room test, a final trial was carried out in two similar, empty, unheated huts. The huts were built of wood, lined with plasterboard, and had concrete floors: the volume of each was calculated as 5,330 cu. ft. After liberating the flies, insecticide was applied through a Maney sprayer at the rate of 25 ml./1,000 cu. ft. Sugar and water were provided as food for the flies. The temperature was 23·5° C. at the start and finish of the experiment. The data obtained are summarised in Table V.

TABLE V.

Hut Test of Toxicity to Houseflies of 0·03 per cent. Pyrethrins + 0·1 per cent. DDT in Pool Burning Oil.

Time after spraying	Hut 1 (0·03 per cent. pyr. + 0·1 per cent. DDT)	Hut 2 (Standard Fly Spray)
	2,000 flies	2,000 flies
5 mins.	90 per cent. knock-down	90 per cent. knock-down
10 mins.	94 per cent. knock-down	95 per cent. knock-down
20 mins.	96 per cent. knock-down	96 per cent. knock-down
30 mins.	96 per cent. knock-down	97 per cent. knock-down
1 hour	97 per cent. knock-down	97 per cent. knock-down
2 hours	98 per cent. knock-down	96 per cent. knock-down
3 hours	98·5 per cent. knock-down	93 per cent. knock-down
24 hours	100 per cent. dead	85 per cent. dead

The percentage knock-down and kill were found by counting the numbers of flies still active after the appropriate periods of time. At the 24 hours count only about 1,000 flies could be accounted for in hut 1 and somewhat fewer in hut 2. The chances of escape for the flies were considered before the experiment to be relatively small, yet it would seem that the flies had taken advantage of every possible loophole. The greater part of the loss of flies may have occurred in the interval between their liberation and the start of spraying. In these circumstances the 100 per cent. kill in hut 1 means that there was no living fly present at the time of the count, the trend of the knock-down figures indicating that no recovery of any affected flies had taken place. The 85 per cent. kill in hut 2 probably expresses the maximum possible kill, since the knock-down values showed flies were starting to recover after the first hour's exposure.

Under these conditions there was nothing to choose between the two insecticides in rate of knock-down, but the pyrethrum-DDT spray was again greatly superior in kill. The marked difference between the insecticides in the knock-down test in the small chamber is due to the stringency of the test, which discloses differences not detectable in practice. With straight pyrethrum sprays it is easier to achieve a good knock-down than a high kill, and the dose for practical use will therefore be governed by the lethal action of the insecticide. Comparison of the knock-down caused by pyrethrum-DDT mixtures and by Standard Fly Spray should therefore be made, except in special circumstances, at a level of dosage which will ensure a reasonably high kill by the Standard Fly Spray.

Pyrethrum-DDT-Sesame Oil Mixture.

Sesame oil (Eagleson, 1942; Parkin & Green, 1944), isobutylundecylenamide (Weed, 1938) and certain other substances, themselves relatively non-toxic, can markedly increase the toxicity of pyrethrins when added in quite small amounts. Preliminary experiments in the fly spray chamber showed that the knock-down of a spray containing 0·02 per cent. pyrethrins +0·05 per cent. DDT in Pool burning oil could similarly be increased by the inclusion of 5 per cent. v/v of an active sesame oil or 0·5 per cent. v/v isobutylundecylenamide.

The effect of sesame oil was then tested by atomisation of the insecticides with a Maney hand sprayer at the rate of 25 ml./1,000 cu. ft. in rooms in which flies had been liberated. The rooms were centrally heated and had temperatures of 27–28·5° C. at the time of spraying. The data obtained are set out in Table VI.

TABLE VI.

Room Test of Effect of Addition of Sesame Oil on Toxicity to Houseflies of a Pyrethrum-DDT Spray.

Time after spraying	Room 1 (2,000 cu. ft.)	Room 2 (2,500 cu. ft.)	Room 3 (1,500 cu. ft.)
	Standard Fly Spray	0·02 per cent. pyr. + 0·05 per cent. DDT + 5 per cent. sesame oil	0·02 per cent. pyr. + 0·05 per cent. DDT
	700 flies	900 flies	500 flies
5 mins. ..	60 per cent. knock-down	50 per cent. knock-down	40 per cent. knock-down
10 mins. ..	90 per cent. knock-down	90 per cent. knock-down	75 per cent. knock-down
30 mins. ..	94 per cent. knock-down	96 per cent. knock-down	80 per cent. knock-down
1 hour ..	94 per cent. knock-down	97 per cent. knock-down	80 per cent. knock-down
2 hours ..	90 per cent. knock-down	97 per cent. knock-down	80 per cent. knock-down
24 hours ..	90 per cent. dead	97 per cent. dead	95 per cent. dead

These data confirmed earlier results that 0·02 per cent. pyrethrins + 0·05 per cent. DDT was inferior in knock-down effect but superior in kill to the Standard Fly Spray. When 5 per cent. sesame oil was included, however, the knock-down effect was considerably increased, so that the pyrethrum-DDT-sesame oil mixture became about equal to the Standard Fly Spray in knock-down and was slightly superior to the pyrethrum-DDT mixture without sesame oil in kill, although at high levels of mortalities differences are naturally reduced.

Storage of Pyrethrum-DDT Mixture.

As soon as it had been shown that the knock-down and lethal effects, respectively, of pyrethrum and DDT could be combined, it was anticipated that information would eventually be required on the compatibility of these constituents during storage for long periods. The following solutions in Pool burning oil were therefore prepared from concentrates TA.21 and TA.29 :—

Solution 1.—0·02 per cent. pyrethrins +0·05 per cent. DDT ;

Solution 2.—0·04 per cent. pyrethrins ;

Solution 3.—0·10 per cent. DDT.

These solutions were stored in glass stoppered bottles in the dark at 27·5° C. for 17 months, when a chamber test on flies was made of three solutions, each containing 0·02 per cent. pyrethrins + 0·05 per cent. DDT in Pool burning oil, namely,

A. Solution 1 ;

B. A similar solution made by mixing equal parts of solutions 2 and 3 ;

C. A similar solution freshly prepared from concentrates TA.21 and TA.29, which were known from continual trial in experiments to have retained their respective toxicities under the particular conditions of their storage.

The results are summarised in Table VII.

TABLE VII.

Chamber Test of the Toxicity to Houseflies of stored and freshly-prepared Mixtures of 0·02 per cent. Pyrethrins + 0·05 per cent. DDT in Pool Burning Oil.

Insecticide	No. of flies	K–D per cent.	Mean K–D per cent.	No. of flies caught	Kill per cent.	Mean kill per cent.
Mixture freshly prepared	87	96·4		87	73·6	
	88	93·2		88	70·4	
	82	96·3		82	78·0	
	75	94·6	95·2	75	74·7	74·1
Solution 1 (stored 17 months).	84	89·2		83	77·1	
	78	85·8		76	81·5	
	76	84·2		74	64·8	
	72	83·3	85·8	68	73·5	67·3
Mixture of solutions 2 and 3 (stored 17 months).	94	96·8		94	69·1	
	72	94·4		70	61·4	
	78	89·7		75	66·7	
	87	94·3	94·0	85	70·5	67·3
Controls..	107				6·5	
	74				9·4	
	85				0	
	84				7·1	5·7

The state of paralysis of the flies knocked down was not so complete with the stored sprays as with the freshly-prepared solution : this was particularly marked with solution 1. In addition, a slight fall in the percentage kill was noted with the mixture made from the components stored separately. The deterioration in toxicity was considered too slight to be of practical importance and it was not thought worth while, at this stage of storage, to undertake tests to discover whether one or both of the toxic constituents had been affected.

Comparison of DDT Samples.

A comparison was made of the toxicities of TA.29 and three other samples of DDT, *viz.* :—

TA.30—Crude granular product.
TA.31—TA.30 ground under alcohol.
TA.32—TA.30 recrystallised from alcohol.

At the time of the assay the purity of these substances in terms of the *p*, *p*′-compound was unknown. In order to avoid a complete mortality of the flies after 24 hours, it would have been necessary to use such low concentrations of DDT that little knock-down in 10 mins. could have been expected, with consequent difficulty in catching the insects for observation of kill. This difficulty was largely overcome by testing the DDT samples in combination with pyrethrins. Solutions were made of 0·03 per cent. pyrethrins (TA.21) + 0·1 per cent. DDT in Pool burning oil, *i.e.* the mixture recommended for practical use, and tested in the small chamber at the reduced dosage of 1 ml. At this level of dosage, 100 per cent. knock-down was not attained within 10 mins. and it was not possible to catch all the flies. In Table VIII, the numbers collected are recorded and the percentage mortalities, which are based on these figures, are therefore somewhat high.

TABLE VIII.

Comparison of Toxicity to Houseflies of Four Samples of DDT (0·1 per cent.) when combined with Pyrethrins (0·03 per cent.) in Pool Burning Oil.

DDT sample	No. of flies	No. of flies caught	Kill per cent.	Mean kill per cent.	Purity of DDT per cent. w/w
TA.29	81	72	75·0		
	89	85	74·1		
	91	88	81·8		
	85	79	75·9	76·8	74·6
TA.30 (crude)	99	91	58·2		
	90	79	57·0		
	95	89	58·4		
	82	74	67·6	59·8	67·3
TA.31 (ground under alcohol).	87	75	86·7		
	89	77	88·3		
	91	78	69·2		
	85	73	80·8	81·2	80·6
TA.32 (recrystallised from alcohol).	86	78	75·6		
	101	89	91·0		
	79	70	85·7		
	83	73	87·7	85·1	98·7
Controls			0		
			0	0	

In the last column of Table VIII are given the values for the percentage purity of the different samples, as subsequently determined by chemical analysis in the laboratories of the Chief Chemical Inspector, Ministry of Supply. There is good agreement between the biological and chemical assays which indicates that toxicity is closely related to chemical purity.

Knowing the purity of the samples, solutions in Pool burning oil were made from each to contain 0·03 per cent. w/v of the pure *p*, *p*′-compound plus 0·04 per cent. w/v pyrethrins, to ascertain whether the impurities contributed to the toxicity of the DDT.

These concentrations were selected from preliminary trials to avoid the excessively high mortalities to be expected from 0·1 per cent. pure *p*, *p′*-compound + 0·03 per cent. pyrethrins (Table VIII). The mixtures were tested as above at a dosage of 1 ml. and the results are recorded in Table IX.

TABLE IX.

Comparison of Toxicity to Houseflies of four Solutions, each containing 0·03 per cent. pure *p*, *p′*-compound and 0·04 per cent. Pyrethrins in Pool Burning Oil, but using DDT Samples of different Purities.

DDT sample	Purity per cent.	No. of flies	No. of flies caught	Kill per cent.	Mean kill per cent.
TA.29	74·6	127	126	38·1	
		115	111	37·8	
		104	104	44·2	
		121	117	49·6	42·4
TA.30	67·3	124	120	45·0	
		112	108	37·9	
		115	112	31·3	
		137	133	42·1	39·3
TA.31	80·6	110	108	37·0	
		105	103	44·6	
		109	106	47·1	
		111	106	38·7	41·8
TA.32	98·7	119	117	45·3	
		125	124	41·9	
		112	109	46·8	
		110	109	42·2	44·0
Controls		121		0	
		114		0·9	
		117		0·9	0·6

The data indicate that the impurities present in the DDT samples used exerted no toxic effect on the flies when tested in combination with pyrethrins. In a separate test, 1 ml. of 0·04 per cent. pyrethrins alone killed only 4·9 per cent. of the flies.

Toxicity of DDT in Alcohol.

In some parts of the world, alcohol is likely to be more available as a carrier for insecticidal materials than kerosene. A room test was therefore carried out to determine the toxicity to houseflies of a 1 per cent. w/v solution of DDT (TA.29) in industrial methylated spirit. The insecticide was applied with a Maney hand sprayer at the rate of 25 ml./1,000 cu. ft.: the temperature at the time of spraying was 23·5° C.

During the first 10 mins. of exposure all the flies were irritated, but only about 10 per cent. were knocked down. After 30 mins. a 95 per cent. knock-down was recorded, followed by 100 per cent. kill in 24 hours. It was therefore concluded that 1 per cent. DDT in industrial methylated spirit is much slower in knock-down action than 1 per cent. DDT in kerosene but can be used with confidence to control flies, if kerosene is not available and rapid knock-down is not of prime importance.

Residual Film Effect of DDT.

Early in the course of the work, a room test was made to compare the toxicities to houseflies of 1 per cent. DDT in Pool burning oil, 0·02 per cent. pyrethrins + 0·05 per cent. DDT in Pool burning oil, and the Standard Fly Spray, when applied as very finely atomised sprays at the relatively low dosage of 10 ml./1,000 cu. ft. The

1 per cent. DDT spray proved greatly superior to the others. With the Standard Fly Spray, however, the knock-down during the first 3 hours increased progressively in a way which was atypical of such a straight pyrethrum spray and, after 30 mins. exposure, more and more flies showed symptoms similar to those caused by DDT. This effect was ascribed to the residual film of DDT probably left in the room from a previous spraying with 1 per cent. DDT in Pool burning oil. A special experiment was therefore immediately undertaken to evaluate the practical importance of this effect.

A room of 2,000 cu. ft. capacity was treated with 156 ml. of 1 per cent. DDT (TA.29) in Pool burning oil, applied to the walls and ceiling as a coarse spray from a paint spray gun : the floor was treated, incidentally, by the spray which did not adhere to walls or ceiling. This application was equal to a mean dosage of 2·0 mg. TA.29/sq. ft. for the whole area, but residues from earlier experiments in the room might have caused the total deposit to approach a maximum of about 10 mg./sq. ft. Batches of 1,000 flies were liberated at intervals after spraying to investigate the retention of toxicity of the film over a period of time. Sugar and water were provided for the flies during the exposure period, and it was shown in an untreated room that, under the conditions of the experiment, flies could exist for 48 hours without mortality. The results are shown in Table X.

TABLE X.

Toxicity to Houseflies of a Residual Film of DDT on the Walls of a Room.

Age of film	Time after release of flies							
	10 min. K–D per cent.	30 min. K–D per cent.	1 hr. K–D per cent.	2 hr. K–D per cent.	3 hr. K–D per cent.	6 hr. K–D per cent.	24 hr. Kill per cent.	48 hr. Kill per cent.
15 mins.	7	60	80	90		99·8	100	
1 day			8	15			100	
2 days	1		10		50	99	100	
3 days					30		100	
8 days					30	75	100	
2 weeks							100	
3 weeks							99	100
4 weeks							98	100
5 weeks							97	100
6 weeks							90	98
7 weeks							25	50
10 weeks							5	10

The residual film formed by spraying 1 per cent. DDT in Pool burning oil on to the absorbent walls and ceiling of a room clearly had a marked toxicity to flies. This toxicity was evident long after the time required for evaporation of the solvent. The film, which was a relatively light one, lost toxicity fairly rapidly during the first three days after application, as shown by the counts of knock-down, and then, as shown by fly mortality, lost toxicity more slowly up to an age of six weeks ; after this the film deteriorated rapidly.

The residual film effect of DDT obviously has great promise for reduction of fly populations, especially in kitchens, stables and latrines. Several practical trials of DDT films have been carried out with success against both the housefly, *Musca domestica*, and the stable fly, *Stomoxys calcitrans*. The following is an example in which detailed observations were possible.

A small room, used as a kitchen, had walls and ceiling of an area of about 630 sq. ft.; of this 100 sq. ft. was painted wood framing and the remainder painted fibreboard from which most of the paint had flaked away leaving a very absorbent surface.

At the beginning of August, 1944, a coarse spray was applied to the walls and ceiling by means of a paint spray gun working with an air pressure of 15 lb./sq. in. The DDT was applied as a 2·5 per cent. w/v solution of sample TA.75 (containing 77·0 per cent. *p*, *p′*-compound) in Pool burning oil at the rate of 1·6 ml./sq. ft. Of this probably not more than 75 per cent., *i.e.* 30 mg. pure DDT/sq. ft., adhered to the surface. Counts made on each of the six days before treatment showed an average natural population of 150–200 flies. Subsequent counts were as follows :—

Time after spraying	*No. of active flies*
1 day	0
4 days	1
6 days	10
8 days	8
10 days	12
2 weeks	10
1 month	6
2 months	3

At each of these observation periods, dead and affected flies were found on window ledges, etc. The counts were discontinued after two months because of the onset of colder weather.

Finally, the painted walls of the constant temperature–constant humidity rooms (27·5° C. and 60–65 per cent. R.H.), in which flies are bred and the test chambers housed at this Laboratory, have been heavily treated with DDT in Pool burning oil All escaping flies are still incapacitated within three hours, although it is some 12 months since the spray was applied.

Symptoms of DDT Poisoning of Flies.

Within 1 min. of being sprayed in the small chamber with 2 ml. of 0·05–1·0 per cent. w/v DDT (TA.29) in Pool burning oil, the flies fly about excitedly. Shortly afterwards those alighting on the glass front of the chamber lose their grip and begin to slide slowly downwards. Almost all the insects soon cease to fly, and run actively on the floor of the chamber, frequently stopping to " clean " front and hind legs, wings, and head with great energy : at this stage the flies will take short flights if disturbed. Up to this point, the effects are similar to those of Pool burning oil alone, but, subsequently, symptoms definitely due to DDT poisoning become evident. The first DDT symptom, which generally follows very rapidly after the cessation of flight, is the failure of the legs to support the weight of the body, and loss of co-ordination between them. The hind legs are not always the first to be affected and all or some legs on one side may be much more severely paralysed than those on the other side of the body. The badly affected flies now roll on to their backs and kick their legs frantically in the air, tending at the same time to extrude the proboscis. A few flies can take off from their backs for very short uncontrolled flights. Whether the flies can become airborne or not, the wings can still be vibrated forcefully, resulting in a symptom of DDT poisoning which is generally recognisable in practical spraying, namely, a loud buzzing of the semi-paralysed flies. The general convulsive activity dies down and the flies may lie for several hours, according to the concentration of DDT used, in a comatose state with continuous marked tremors and occasional spasms of the legs, which are very strongly flexed at the femoro-tibial joints. Many flies have the proboscis half to fully extruded with a drop of clear regurgitated fluid on the labellar lobes. The tremors slowly become less marked until death eventually supervenes. The occasional autotomy of legs by affected flies, recorded by Läuger, Martin and Müller (1944) has never been observed by us : Wiesmann and Fenjves (1944) have noted this phenomenon in other species of insects. There is a close similarity between the clinical symptoms of DDT poisoning of flies and warm-blooded animals, which show hyperexcitability and generalised fine and coarse tremors ending in flaccid or spastic paralysis with occasional tonic and clonic convulsions preceding death by respiratory failure (Smith & Stohlman, 1944).

Flies killed by DDT die with the proboscis extended and the legs usually strongly flexed at the femoro-tibial joints. Some 30 per cent. of the females have the ovipositor partly extruded.

In contradistinction to that of DDT, the action of pyrethrum is much more rapid. A dose of 2 ml. of 0·02–0·1 per cent. w/v total pyrethrins sprayed into the small chamber results immediately in excited flight and slipping of the feet on glass. The flies soon cease to fly, and crawl on the floor with the body weight scarcely supported by the legs, which quickly become paralysed in the sequence—hind, middle, fore legs. The flies can still vibrate their wings and engage in short uncontrolled flights but, more usually, vibration of the wings results in the fly spinning on the front of its head. This violent movement does not last long and the flies roll over on their backs. They lie quietly with the legs loosely flexed, although, usually, a few flies have one or two legs fully extended at an abnormal angle to the body. Any leg movement is slow and intermittent, unlike the continuous, vigorous kicking observed with DDT. Most flies have the proboscis extended, with a drop of clear, regurgitated fluid at the tip. About 25 per cent. show tremors of the legs and head. With the lower concentrations of pyrethrins there is a greater tendency for the female flies to evert their ovipositors. All movements slowly subside until death supervenes.

After death, a small proportion of the flies can generally be seen to have one or more legs partially to fully extended at the femoro-tibial joint. Similarly, a small proportion have the proboscis retracted. It is not easy, however, to distinguish flies killed by pyrethrum from those killed by DDT.

It is interesting to observe that flies exposed to a sub-normal dose of the mixture of 0·03 per cent. pyrethrins + 0·1 per cent. DDT in Pool burning oil show symptoms suggesting that the two insecticides act independently of one another. During the first 1–2 hours of exposure, the symptoms are typically those of pyrethrum, and about the second hour there may be partial recovery from the effects of the pyrethrum knock-down, only to be followed by a relapse as the flies begin to show the typical symptoms of DDT poisoning which eventually lead to death.

Discussion.

There can be no doubt, as judged by the results presented in this paper, of the value of DDT for incorporation in fly sprays. The use of DDT, and closely related compounds, in insecticidal emulsions and dusts is dealt with in British Patent Specifications 547, 871 and 547, 874 of 15th September, 1942. The patents describe the preparation of DDT from chlorbenzene and chloral, reacting in the presence of concentrated sulphuric acid. The pure product, m.p. 110° C., consists of colourless needle-like crystals, practically insoluble in water, but soluble to a greater or lesser extent in numerous organic solvents. Present commercial-scale products contain about 65–75 per cent. of the pure p,p'-compound and are soluble to the extent of about 6 per cent. w/v in Pool burning oil at 20° C. and about 3 per cent. w/v in odourless distillate at 20° C. The pure chemical has a weak fruity odour, and this odour can easily be recognised in the slightly more strongly smelling crude preparations. In sprays, the odour of DDT is generally masked by that of the solvent.

In our experience, sprays containing up to 2 per cent. w/v DDT are non-irritant to human beings during application, excluding the slight symptoms associated with the kerosene, but at a strength of 5 per cent. some irritation of the eyes and throat has been experienced. Although some reports on the toxicity of DDT to animals have been published, there is, as yet, insufficient information available to enable its toxicity to human beings to be assessed under all conditions in which it is most likely to be used in practice.

The advantages of DDT for fly sprays are as follows: it can be prepared synthetically; it is almost odourless; it will not stain fabrics, etc.; it appears to have no marked irritant effect on the operators at low concentrations; it is extremely lethal to flies, both in solution and in the solid form after deposition on walls, etc., from volatile solvents. Its main disadvantage is its slow rate of action on flies, unless used at a concentration of at least 1 per cent. w/v, but even at this level affected flies produce an unwelcome buzzing sound for an hour or more before the wing muscles become paralysed.

The disadvantage of slow action can be overcome by the admixture with DDT of a small amount of pyrethrins, which have a very rapid paralytic effect. We have shown that these two materials are compatible in kerosene solution and that the mixture remains effective during a long period of storage in glass and in the dark. It has also been found that a solution of 0·03 per cent. w/v total pyrethrins and 0·1 per cent. w/v DDT (of 74·6 per cent. purity) in Pool burning oil makes a fly spray almost equal in knock-down effect and greatly superior in killing power to the O.T.I., which is used in the U.S.A. as a reference standard for fly sprays. Equally encouraging results have been obtained by Gersdorff and McGovran (1944), who tested a similar mixture, save that the solvent was a deoderised kerosene, by the turntable method. An increase in the speed and intensity of knock-down can be gained by the incorporation in the pyrethrum-DDT mixture of a suitable activator for pyrethrins, such as sesame oil or isobutylundecylenamide.

A particularly important outcome of the experiments described is the discovery of the residual film effect of DDT on flies: similar observations have since been reported in the U.S.A. by Lindquist and others (1944), van Leeuwen (1944) and Blakeslee (1944). Such an effect will be of great practical value for the reduction of fly populations in certain types of buildings in which flies may be a nuisance, *e.g.*, dwelling houses, shops, canteens, hospitals, stables, etc. Suitable application of DDT should ensure that all flies resting in a building during the night will be moribund or dead before morning and that the only fly nuisance will be that due to the daytime entry of flies. That such a practical result can be obtained has already been shown by full-scale experiments, and a more detailed laboratory investigation of this residual effect has been started. Campbell and West (1944) have reported in this connection that DDT shows a film effect for at least two months when incorporated at 0·5–5·0 per cent. in oil-bound water paints, although it will not work in oil or synthetic varnish paints.

The place of DDT in the post-war development of fly sprays is assured and there will no doubt be considerable improvements in methods for its application, but when quick knock-down is essential it will be necessary to incorporate with it some more rapidly acting paralytic agent, such as pyrethrum. As we have already demonstrated, concentrations can be so chosen that the pyrethrins will maintain the flies in a comatose state until the more slowly developed toxic effects of the DDT can supervene and ensure death.

Summary.

DDT (*p,p'*-dichlordiphenyl-trichlormethyl-methane) has been shown to be very toxic to the housefly, *Musca domestica*, L., when applied as a spray containing 0·1 per cent. w/v or more in kerosene. DDT at 1 per cent. gives an effective spray for practical use, but at lower concentrations the speed of knock-down is too slow. This disadvantage can be overcome by the admixture of a small amount of pyrethrum. A mixture of 0·03 per cent. w/v total pyrethrins and 0·1 per cent. w/v DDT in kerosene is recommended as a suitable fly spray for practical use. This mixture can be stored in glass bottles in the dark for at least 17 months at 27·5° C. without marked deterioration. Its toxicity may be increased by the incorporation of a suitable activator, *e.g.*, sesame oil or isobutylundecylenamide.

The impurities in crude preparations of DDT appear to exert no toxic effect on houseflies.

DDT acts more slowly when dissolved in industrial methylated spirit than in kerosene.

Attention is drawn to the residual film effect of DDT on walls, etc., and an example is given to show how this effect was employed in the control of a fly population in a kitchen.

The symptoms of poisoning of flies by DDT are compared with those caused by pyrethrum. DDT is relatively slow in action ; it is a severe irritant, causing the flies to buzz violently at one stage ; it induces marked tremors during the coma preceding death ; and, at death, it causes the legs to be tightly flexed at the femoro-tibial joint. When the pyrethrins and DDT are mixed in a spray, these constituents, so far as can be judged from the train of toxic symptoms, act independently, so that the rapid paralytic effect of the pyrethrins keeps the insects immobile until the slow lethal effect of the DDT supervenes.

This work has been carried out as part of the programme of research of the Pest Infestation Laboratory, and this account is published by permission of the Department of Scientific and Industrial Research.

References.

Blakeslee, E. B. (1944). DDT as a barn spray in stablefly control.—J. econ. Ent., **37**, pp. 134–135.

Campbell, G. A. & West, T. F. (1944). Persistence of DDT in oil-bound water-paint.—Nature, London, **154**, p. 512.

Eagleson, C. (1942). Sesame in insecticides.—Soap & sanit. Chem., **18** (12), pp. 125, 127.

Gersdorff, W. A. & McGovran, E. R. (1944). Laboratory tests on houseflies with DDT in contact sprays.—J. econ. Ent., **37**, p. 137.

Läuger, P., Martin, H. & Müller, P. (1944). Ueber Konstitution und toxische Wirkung von natürlichen und neuen synthetischen insektentötenden Stoffen.—Helv. chim. Acta, **27**, pp. 892–928.

Lindquist, A. W., Madden, A. H., Wilson, H. G. & Jones, H. A. (1944). The effectiveness of DDT as a residual spray against houseflies.—J. econ. Ent., **37**, pp. 132–134.

Parkin, E. A. & Green, A. A. (1944). Activation of pyrethrins by sesame oil.—Nature, London, **154**, pp. 16–17.

Smith, M. I. & Stohlman, E. F. (1944). Pharmacologic action of 2, 2-bis (p-chlorophenyl)-1, 1, 1-trichlorethane and its estimation in the tissues and body fluids.—Publ. Hlth Rep., Wash., **59**, pp. 984–993.

van Leeuwen, E. R. (1944). Residual effect of DDT against houseflies.—J. econ. Ent., **37**, p. 134.

Weed, A. (1938). New insecticide compound.—Soap & sanit. Chem., **14** (6), pp. 133–134.

Wiesmann, R. & Fenjves, P. (1944). Autotomie bei Lepidopteren und Dipteren nach Berührung mit Gesarol.—Mitt. schweiz. ent. Ges., **19**, pp. 179–184.

FURTHER NOTE ON THE CLASSIFICATION OF THE DIPRIONIDAE (HYMENOPTERA, SYMPHYTA).

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When I was revising the genera of the Diprionidae (Benson, 1939), the British Museum had very scanty material of *Neodiprion* other than of the sole Palaearctic representative of the genus, *N. sertifer* (Geoffr.). The few North American specimens of the genus, only five females belonging to five species and a few unnamed males, were all ancient specimens in poor condition and pinned so as to obscure the shape of the scutellum. I had therefore to supplement my knowledge of Nearctic *Neodiprion* by information kindly sent to me by the late Miss Grace Sandhouse, gleaned from specimens in the collections at Washington. Atwood and Peck (1943), in dealing with long series of Canadian *Neodiprion,* have since found that the shape of the scutellum, as defined in my paper, is rather difficult to interpret and is liable to considerable individual variation.

This difficulty can I believe be overcome by a slight re-arrangement of my key. Firstly, I now propose to recognise two sub-families, which I consider fully justified, on the basis of still further morphological differences correlated with the known host-plant differences :—

A. Wings densely pubescent and with ciliate margins ; anal cell of forewing divided by a medial constriction ; transverse median vein oblique. Male antenna uniramose and with flagellum strongly curved apically. Attached to Cupressaceae.

Genera : *Monoctenus* (on *Juniperus*) and *Augomonoctenus* (on *Libocedrus*). Monocteninae.

B. Wings with sparse pubescence and naked margins ; anal cell of forewing only slightly contracted sub-basally, not divided, and with a cross-vein behind the middle ; transverse median vein sub-erect. Male antenna biramose and with flagellum not strongly curved apically. Attached to Pinaceae.

Genera : *Diprion, Gilpinia, Macrodiprion, Microdiprion, Neodiprion, Nesodiprion, Prionomeion,* and *Zadiprion.* Diprioninae.

In making a key to the Diprioninae, a more natural arrangement would result from interposing my couplet 3 in place of couplet 1, thus separating off *Diprion,* Schrank, and *Macrodiprion,* Enslin, with their small cenchri and large metascutellum, from the rest. To divide the rest the following would be a better couplet 2.

2. Anal cell of hindwing with a stalk much longer than the greatest breadth of the cell. Abdomen with tergites densely rugulously sculptured transversely ; scutellum blunt in front.

Genera : *Gilpinia,* Benson, and *Prionomeion,* Benson, separated from each other in my previous couplet 5.

—. Anal cell of hindwing with a stalk at most scarcely longer than greatest breadth of the cell. Abdomen usually with tergites polished and with indistinct rugulous sculpture, *or* with scutellum produced acutely in front.

Genera : *Nesodiprion,* Rohwer (separated on the basis of its exceptionally long apical hind-tibial spurs as in my previous couplet 1), *Microdiprion,* Enslin, *Neodiprion,* Rohwer, and *Zadiprion,* Rohwer (these three separated in couplets 8 and 9 of my previous key).

In listing the species of the *socia*-group of *Gilpinia*, I omitted to mention *G. variegata* (Htg.). Since my paper was published, Takeuchi (1940) has contributed a valuable paper on the DIPRIONIDAE of Japan, thus partly filling in the great gap that exists in our knowledge of these insects in Asia. In this paper he described several new species of *Gilpinia*, some of them very close to well-known European species, but of special interest from the bio-geographical point of view is his recording of *Neodiprion sertifer* from Korea and Honshu, of "*Gilpinia polytoma*, Htg." from Korea, Honshu and Hokkaido, and *G. abieticola*, D.T., from Honshu.

References.

ATWOOD, C. E. & PECK, O. (1943). Some native sawflies of the genus *Neodiprion* attacking pines in eastern Canada.—Canad. J. Res., (D) **21,** pp. 109–144.

BENSON, R. B. (1939). On the genera of the Diprionidae (Hymenoptera Symphyta).—Bull. ent. Res., **30,** pp. 339–342.

TAKEUCHI, K. (1940). A systematic study of the suborder Symphyta (Hymenoptera) of the Japanese Empire. 3, Diprionidae.—Tenthredo, **3,** pp. 187–199.

EXPERIMENTS WITH DDT IN SOLUTIONS AND EMULSIONS AGAINST MOSQUITO LARVAE IN WEST AFRICA.

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Introduction.

In the work here described it was not intended to control mosquito larvae, but to assess the relative effectiveness of different preparations containing DDT (dichlor diphenyl trichloroethane). I was, therefore, not much interested in doses that might be regarded as safe in practice, for one cannot compare two insecticides if they are both giving a kill of approximately 100 per cent. In order to get the comparisons which were required, I cut doses down till the materials began to fail, and determined that point as accurately as possible. In many points the methods are similar to those already described by Major C. R. Ribbands, R.A.M.C., in an unpublished report.

The work was carried out in the neighbourhood of Takoradi, Gold Coast, from mid July to the end of September, 1944. I am grateful to the Director General of Scientific Research and Development of the Ministry of Supply, on whose behalf the work was done, for permission to publish this paper.

The Environment.

The area round Takoradi, Gold Coast, is covered entirely by red soil or rock, undulating and cut by numerous small streams. Many of the waters contained a red material presumed to be ferric hydroxide, perhaps much mixed with micro-organisms. In places this lay as a thick floccular layer at the bottom, and also formed a surface scum. There were also numerous flat depressions, forming characteristic shallow swamps, only a few inches deep, with clear running water. The dominant plant was a blue-flowered *Tradescantia*, forming a dense mat 6–12 inches high, concealing most of the water surface.

In this part of the Gold Coast there is a large village population and much farm land. The wetter land is thrown up in ridges with ditches between, which are generally twenty yards long, two feet wide and a few inches deep. These hold water (or can easily be blocked and flooded) and a series of them provides excellent facilities for experimental work. Much work was done in an area (the Vegetable Farm) of this type put at our disposal by the Senior Agricultural Officer, Mr. F. R. Mullan. Experiments were also carried out on road side ditches, but these were often unsuitable owing to iron scum (which reduced, but did not entirely abolish, mosquito breeding).

Rainfall figures are available from Takoradi aerodrome for the actual months covering our work: we are grateful to the Senior Meteorological Officer of the R.A.F. Station for them. The aerodrome is about five miles from the experimental area, and at the same altitude. Monthly totals and rain days (*i.e.*, 0·01 inch or more) are as follows :—

	July	*August*	*September*, 1944
Total, inches	7·42	0·40	0·79
Total, mm.	188·2	10·3	19·7
Rain days	13	9	12

There were no periods of very heavy rain ; the longest completely rainless periods were of eleven days, from 12th and 31st July. Generally there was sufficient rain to maintain breeding, and no floods, but several experiments had to be discontinued owing to drying of ditches.

Methods.

Most of the work was done in a vegetable garden, in which the land had been thrown into ridges some two yards wide with ditches about two feet wide between them. The ditches were connected to one another by cross channels every 20 yards, so that we had a lay-out of many similar lengths of ditch, very close together, admirable for experimental work. The ground was not under cultivation, and we were free to cut or block channels and increase the breeding of *Anopheles*.

The rate of flow of the water in these ditches was measured by Major G. S. James. He tested a number of ingenious ideas, and concluded that the simplest was the best ; he timed the passage of a submerged particle of organic detritus over a measured distance, with a stop watch.

Materials were also tested in what we called *Tradescantia* swamps, a very characteristic type of local water. These swamps form in small wide valleys, and have a hard bottom, which is exceedingly flat, so that the depth of water is uniform, generally four to ten inches. The water is in moderately rapid flow (up to ten feet per minute), over the whole expanse of the swamp. The vegetation is also extremely uniform and consists of two or three species of flowering herbs, of which we could only identify a blue-flowered *Tradescantia ;* these herbs were about a foot high from the water surface and were so dense that the water was invisible in most places. There were no aquatic grasses, and no trees or bushes in these swamps.

All natural waters, however clean they appear, have a surface film on them, which might impede the spread of an oil. It is important to measure the spreading pressure of this natural film, for the oil which one proposes to use must have a higher spreading pressure, otherwise it cannot cover the water. The spreading pressure of these natural films was measured by Dr. B. A. Toms, who used a method recently described by Professor N. K. Adam, F.R.S. (the use of liquids and solutions of standard spreading pressure).

Dr. Toms found that there were often great differences in the pressures required to overcome the films on the ditches. Where the water appeared to be clean its film pressure was uniform, generally five to ten dynes per centimetre, and always under thirty. On many parts of the waters there were visible films, which we called inorganic or iron films (the evidence being slender, and it being probable that the film possesses a considerable organic constituent). These films tend to be carried by wind or small currents and to pile up against a barrier ; they have film pressures exceeding 45 dynes, but if broken mechanically can be driven aside by an oil with a lower spreading pressure than 45 dynes. There were also barriers of filamentous algae with gas bubbles (one could not call them films), which often reached the surface, and were mechanically so strong that an oil exerting 45 dynes per centimetre could not dislodge them.

As an example of the puzzling conditions found one may quote results from a single irrigation ditch. The first part was wide and muddy, with a maximum flow of 1·08 feet per minute : film pressure was uniform, at 5–10 dynes per centimetre. The second part followed after a right angled bend ; it was 20 yards long, rapid but irregular in flow, with maxima of 20 feet per minute ; the film pressures were 15–20 dynes in clean areas, 25–30 in areas where scum accumulated, and over 45 in one place. The third section resembled the first, for it was slow and clean, and had a uniform film pressure of 5–10 dynes.

The method of assessing the larvae was by collecting with a soup ladle, taking ten dips, and more in large breeding places. This was always done for several days before an insecticide was put down, as the day to day fluctuations are so great ; see Tables I IV below. Ten dips as a measure of population is not really satisfactory and can only reveal major changes. One fault of the method is that the larvae may be highly localised, so that successive dips at yard intervals along the ditch give widely discrepant results, even if one chooses " likely spots ". As extreme examples one may quote :—

(*a*) Ten dips in a ditch, at yard intervals, gave the following numbers of first-stage *Anopheles* larvae ; 30,2 (four times), 1,1,0 (three times).

(*b*) Ten dips in a *Tradescantia* swamp, at intervals of a pace or two, gave Culicine larvae as follows : 23, 5, 2, 1, 1, 0 (five times).

All dipping was carried out by myself, or by Staff Sergt. F. Lemmon, R.A.M.C., who performed a large amount of work with great care.

In recording results we booked larvae under three categories : *An.*, second-, third- or fourth-instar *Anopheles ; An. I.*, first-instar *Anopheles ; Cul.*, Culicines. From many points of view one may disregard *An. I.*, for their presence is not evidence that the insecticide has failed as they may be in course of dying. But the presence of larger larvae (i.e. *An.*) is clear evidence that the insecticide is failing. All through the period of our work, larvae of *A. funestus* formed at least 90 per cent. of all *Anopheles* larvae, in ditches and swamps. Culicines were not identified.

Insecticide solutions were measured with care, and put down (always by myself), with a pipette, drops being spaced as evenly as possible along the length of the ditch. All the liquids had high spreading pressures, and this simple method did result in a good covering of the surface. On the *Tradescantia* swamp, a measured volume was put down by Maney sprayer, as evenly as possible over the whole area. The jet was pointed down, but one cannot know what proportion of the spray stayed on the herbage, or reached the water surface, or was carried away by the wind.

The following materials were studied :—

(*a*) *Mixture A* made by dissolving DDT in two volumes of lubricating oil (Pool Grade 3, s.g. about 0·9) and one volume Amoa A.S.X. (an oil soluble emulsifier) : the DDT content is adjusted to give a content of 5 per cent. w/w of pure DDT (*i.e.* the pure para para compound). Diluted to 1 : 10 this makes a very lasting emulsion with almost any type of natural water, and is convenient to handle at that dilution. When dropped or sprayed on water the emulsion breaks, covering the water surface with numerous small lenses of oil in which DDT is dissolved. These lenses cannot be sunk by rain. The emulsion has a spreading pressure of 40–50 dynes per centimetre on water, so would be expected to spread readily on any ordinary waters and to penetrate vegetation very readily. A disadvantage of the method in its present form, is that one cannot detect by eye whether an area has been treated.

(*b*) *Dieseline Solution of DDT.*—The DDT (a commercial sample, about 60 per cent. pure) was dissolved in a locally available dieseline : generally a 5 per cent. concentration of pure para para DDT was used, but for putting on very small doses, a 0·5 per cent. The dieseline had a spreading pressure on water of 21 dynes per centimetre. This was raised to 23 dynes by addition of 0·25 per cent. commercial oleic acid : this addition was probably unfortunate, for the gain in spreading pressure was slight, and the oleic acid spread over the water in a matter of minutes and prevented the spreading of a further quantity of oil, on one occasion when this had seemed desirable. Generally speaking a satisfactory cover of the surface was obtained.

(*c*) *Mixture C.*—This was made by mixing together the following :—

200 cc. of a naphtha concentrate, which contained 22 per cent. of technical DDT (of which the content of pure para para DDT = 56 per cent.) and 2 per cent. of oleic acid by weight.

400 cc. of a lubricating oil M220 (H.D.50).

400 cc. kerosene (s.g. 0·88).

The mixture therefore contained 2·6 pure DDT per cent. by weight, or 24 mg. per cc.

When this mixture is spread on water and the volatile components have completely evaporated, one is left with lubricating oil containing 5 per cent. pure DDT by weight, also oleic acid and impurities from the technical DDT. The oil is sufficient to maintain all the DDT in solution at 25° C.

Mixture C has a specific gravity of 0·86, a viscosity at 25° C. of 6·2 centipoises, and an estimated spreading pressure of 28 dynes per centimetre.

Conversion Table.

Doses of DDT as a larvicide are already expressed in so many ways that a conversion table seems necessary, both for weights of DDT and for volumes. One is dealing in all cases with a 5 per cent. solution of DDT (w/w).

0·10 cc. solution/sq. yard = 0·005 gm. DDT/sq. yard.
= 0·006 gm./sq. metre.
= 24 gm. *or* 0·8 oz./acre.
= 15·4 kg. *or* 34 lb./sq. mile.
0·10 cc./sq. yard = 0·12 cc./sq. metre.
= 480 cc. *or* 0·45 Imp. quarts *or* 0·56 U.S.A. quarts/acre.
= 310 lit. *or* 68 Imp. gals. *or* 85 U.S.A. gals./sq. mile.

Results.

1. *Oils without DDT.*—In order to be certain that the results observed were due to DDT and not to the solvent, a few experiments with oil alone were carried out. They were reassuring, and indicated that in the doses used the oils had no effect on the larvae. For instance, a series of experiments on ditches showed that dieseline plus 0·25 per cent. of oleic acid was without effect on larvae of *A. funestus*, even at 0·5 cc. to the square yard. Kerosene at the same dose was harmless.

In studying the effect of DDT on mosquito larvae one is interested in its relatively long residual effect. For purposes of contrast I required a volatile material which would kill all larvae, but have no effect after a period of a few hours; the use of such a material would give valuable information on the recovery of a larval population. The water was generally at 27 or 28° C. and the lead-free petrol which was available evaporated quickly. To my surprise I found that even 30 cc. per square yard caused no diminution of larvae of *A. funestus* (both first and subsequent instars), or Culicines. The same dose of a mixture of lead-free petrol 80 parts, and xylene 20 parts was also ineffective at this temperature. I failed to find any way of abolishing larvae by a volatile material, but should be disposed to test lead-free petrol containing a small proportion of a less volatile oil such as is used as a larvicide. The resultant very thin film would presumably evaporate quickly: its persistence could be tested by the use of standard mixtures of known spreading pressure.

2. *Results with Mixture A.* A typical result from mixture A is given in Table I. The work was carried out on two ditches (C 17 and C 18) on the vegetable farm. They were 24 yards long, about two feet wide, *i.e.*, area 16 square yards. They were shut off at both ends by temporary blocks, so that the surface was stagnant, though water leaked through the dams. The larvae were about 90 per cent. *A. funestus*, 10 per cent. *coustani*.

Treatment with mixture A diluted 1 : 10 with water, applied by pipette. Ditch C 17 was treated on day 2 with 32 cc. of dilute emulsion (equivalent to 0·2 cc. of undiluted mixture A per square yard).* During the next eight days ditch C 18 acts as control for C 17. Ditch C 18 was then (day 10) given a larger dose equivalent to 0·5 cc. undiluted mixture A per sq. yard.

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* *See* Conversion Table above for equivalents in other systems of measurement.

TABLE I.

Effect of Mixture A, an Emulsion, on two similar Ditches : Number of Larvae in ten Dips.

DAY	DITCH C 17				DITCH C 18				REMARKS
	An.	An. 1	Cul.	Total	An.	An. 1	Cul.	Total	
1	6	15	2	23	3	12	4	19	
2	10	24	9	43	13	11	6	30	C 17 treated.
3	1	0	2	3	11	61	14	86	
4	0	2	0	2	8	59	12	79	
6	2	45	3	50	10	52	8	70	
7	2	32	0	34	6	27	12	45	
8	0	63	3	66	7	17	7	31	
10	5	63	2	70	12	50	5	67	C 18 treated.
11	22	48	3	73	0	0	0	0	
12	19	38	3	60	0	0	0	0	
13	7	21	5	33	0	1	0	1	
14	18	46	1	65	1	0	0	1	
15	35	45	1	81	0	8	2	10	
17	24	44	2	70	0	2	0	2	
19	13	12	6	31	2	9	1	12	
20	9	21	7	37	3	15	0	18	
21	16	33	4	53	0	1	1	2	Both drying up.
22	9	9	5	23	2	10	0	12	
24	3	2	4	9	1	4	3	8	
25	2	6	14	22	6	9	1	16	Still drier.
26	13	33	6	52	4	11	5	20	

Table I illustrates a number of points. It is clear that the treatment of ditch C 17 on day 2 destroyed nearly all the larvae, but it is difficult to say how long it lasted. There were a few " large " Anopheline larvae on days 6 and 7, but there was none on day 8, in contrast with 7 in the control. Are we to say that the treatment on day 2 had an observable effect up to day 4, or to day 8 ? In any case, one disregards the larger number of first-instar *Anopheles* larvae.

The other ditch C 18 was treated on day 10, with a larger dose. This was almost completely successful up to day 17 or perhaps even later, for the counts up to day 24 (and particularly the counts of large larvae) are much lower than in C 17 which may be regarded as control.

Work of this kind was carried out on a total of 16 ditches, some completely stagnant, others with slight currents, especially after rain. In all *A. funestus* was the dominant species. It may be summarised as follows, doses being of ccs. undiluted mixture A (5 per cent. pure DDT) per square yard :—

Dose	*No. of experiments.*	*Kill per cent.*	*Lasting, days.*
0·02	Three	Nil	Nil (but some current, in each experiment)
0·05	Three	0–80	1–2
0·1	Five	Over 80	1–2 (less in current)
0·2–0·5	Five	95–100	7–10

A small isolated " pit on a cross drain " in the vegetable garden was also studied. Its area was 8 × 4 feet (3·5 sq. yards) and depth 18 inches. It contained a considerable number of larvae of *A. funestus* and a few Culicines. No similar water was available as control. For five days before treatment (four counts) the average was *An.* 4, *An. 1* 41, *Cul.* 3, *Total* 48. The pit was then given 17·5 cc. of mixture A diluted 1 : 10 with water (*i.e.*: 0·5 cc. undiluted mixture A per sq. yard). This destroyed all larvae (and also all fish), and afterwards none except *An.* 1 were found for six days : even up to nine days there were extremely few " large " larvae. After that the count rose, and averages over short periods were as follows :—

Period	*An.*	*An. 1*	*Cul.*	*Total*
11–15 days	19	70	0	89
16–21 days	15	103	1	119

That is to say the larval population had recovered by day 11, and contained a normal proportion of large larvae. The population was materially larger than in the days before treatment, which may be accidental or due to the destruction of fish (and possibly other predators) by the rather heavy dose of DDT.

The effect of mixture A on running water is perhaps of particular interest. Work was done on an irrigation channel in the vegetable garden: it was free of grass and weeds. The length studied was 84 yards, and the surface area about 54 sq. yards. The width varied from 1 to 3 feet and there were many rectangular bends. The rate of flow varied greatly; it was below 1 foot per minute in one wide deep spot, and rose to 20 feet per minute in little shallow runnels. This channel was treated with 54 cc. of mixture A diluted 1 : 10 with water (*i.e.*, 0·27 gm. DDT) poured in at the top. The larval populations were as follows, determined by 50 dips along the 84 yards :—

	An.	*An. 1*	*Cul.*	*Total.*
5 days before treatment (mean of four counts).	31	137	1	169
1 day after	3	11	1	14
2 days after	5	72	0	77
3 days after	10	33	0	43

The population was back to normal and with a normal proportion of large larvae, within a week. It is clear that the diluted mixture A, poured in at one spot, was not completely effective and did not reach every part of the surface of the channel, in spite of the great power of spread.

Other experiments with flowing ditches (in which the current at the fastest spots was fifteen to twenty feet per minute) showed that mixture A at about one or two cc. of dilute (1 : 10) emulsion to the square yard gave a 90 or 100 per cent. kill of larvae, and was generally completely effective for a few days.

TABLE II.

Experiments with Mixture A, an Emulsion on two similar *Tradescantia* Swamps : Number of Larvae in ten Dips.

DAY	RAIN Inches	CONTROL SWAMP				TREATED SWAMP			
		An.	An. 1	Cul.	Total	An.	An. 1	Cul.	Total
1	0					3	4	4	11
2	0					7	5	0	12
6	0	7	8	20	35	6	3	21	30
7	0	17	19	3	39	8	9	38	55*
8	0	10	3	3	16	1	0	0	1
9	0	5	12	9	26	1	0	37	38
10	0	11	19	3	33	0	0	92	92
11	0	18	25	4	47	1	1	118	120
12	0·07	12	29	0	41	0	1	116	117
13	0·06	16	50	0	66	1	4	34	39*
14	0·01	18	37	0	55	0	0	1	1
15	0	10	27	0	37	1	0	0	1
17	0·01	13	57	0	70	0	0	5	5
18	0·07	11	77	0	88	0	2	9	11
19	0·01	not done				0	3	3	6
21	0	13	22	0	35	0	2	0	2
22	0	29	75	0	104	5	2	13	20
23	0	8	26	0	34	7	2	1	10
24	0	18	13	0	31	2	1	4	7
25	0	11	27	0	38	10	2	2	14
26	0	13	19	0	32	12	1	32	45

* Treated after larvae counted.

Interesting work was carried out on two shallow uniform *Tradescantia* swamps, described above (Table II). They were about 50 yards apart, very similar in all ways ; the prevalent *Anopheles* was *A. funestus.* The area of the swamp which was treated was 30 × 20 yards, *i.e.*, 600 square yards. The current of water ran through all parts of it very uniformly, at perhaps five to ten feet per minute. On day 7 it was treated with 600 cc. of a 1 : 10 dilution of mixture A, put on very evenly with a Maney hand sprayer, directed downwards, much of the spray lodging on the *Tradescantia* leaves and dripping into the water. A similar treatment but double the dose, 2·0 cc. to the square yard was given to the same area on day 13. The control swamp shows a considerable fluctuation in numbers of larvae and particularly in the proportion of Culicines. The first treatment on day 7 was very successful so far as *Anopheles* is concerned, but was followed two to three days later by a great multiplication of Culicines. They appeared all over the swamp and therefore could not have been the progeny of a single egg mass, and they grew and were not destroyed by any DDT that may have remained. Whether they belong to a species particularly resistant to DDT was not studied. The second treatment (at 2 cc. per square yard) was evidently more lasting than first. Consideration of Table II from day 7 gave one very little ground for thinking that the rain (a steady drizzle) may have washed DDT from the leaves, and made it continue to be effective on the water. It is difficult to define the period over which the second treatment was effective, but it appears to be 9–11 days.

3. *Results from Dieseline with DDT.* The type of result obtained with dieseline and DDT (and 0·25 per cent. oleic acid) is given in Table III. It may be compared with Table I, which gave similar results with mixture A. The ditches on which the work and that with mixture A was done were within a few yards of one another.

TABLE III.
Effect of DDT in Dieseline on two similar Ditches : Number of Larvae per ten Dips.

DAY	DITCH C 13				DITCH C 16			
	An.	An. 1	Cul.	Total	An.	An. 1	Cul.	Total
1	14	24	6	44	0	18	0	18
2	13	23	14	50	9	27	8	44
3	16	43	16	75	4	31	6	41
4	8	109	29	146	5	19	14	38
5	10	86	33	129	4	38	9	51
6	10	74	22	106*	11	23	5	39
7	0	0	0	0	11	46	13	70
9	0	14	0	14	5	28	22	55
10	0	21	4	25	3	31	18	52
11	3	98	3	104	3	17	4	24
12	2	93	8	103	4	40	16	60
13	7	34	5	46	5	21	11	37
14	10	34	9	53	6	38	7	51
16	11	37	3	51	19	23	16	58
17	15	34	8	57	7	37	4	48

* C 13 treated after counting.

Table III shows, before treatment, a considerable day to day fluctuation in the numbers of larvae, and the proportion of *An.* to *An. 1* and so forth : on the whole C 13 carried a larger population of larvae than C 16. On day 6, C 13 was treated with 1·2 cc. of a 5 per cent. w/v solution of pure DDT in the dieseline (and 0·25 per cent. oleic acid), the area being 12 sq. yards. The table shows a complete destruction of larvae, and one may say that the result was satisfactory for four days. Five days after application the effect had disappeared ; large larvae were present, and total larvae greatly exceeded the control.

A curious result was obtained with a permanent roadside ditch (Expt. 2). It was 4–6 feet wide, 40 yards long, and a very slight current ran through it. It had obviously been wet a long time, and carried a rich growth of sedges, *Tradescantia*, etc., and also mats of filamentous algae which filled the ditch and were carried up above the surface by bubbles so as to make a complete mechanical barrier against the spread of oil. The movements of larvae were presumably much limited by the algae. This ditch had a large population of *Anopheles* larvae (*funestus* 80 per cent., *coustani* 20 per cent.), the count for three occasions in the week before application averaging *An.* 15, *An. 1* 20, *Cul.* 5, Total 40 (in 20 dips). It was then treated at 0·2 cc. of 5 per cent. DDT in dieseline and oleic acid per square yard. This was dropped by pipette on the mats of algae, and one could see that it failed to spread. There was, however, a complete kill (except for a few *An. 1*), maintained for six days in spite of heavy rain on the fifth day, which increased the current. Thereafter the counts remained low for a long time, as follows :—

	An.	*An. 1*	*Cul.*	*Total*
Second week	1	7	1	9
Third week	2	4	4	10
Fourth week	1	2	4	7

There seems no doubt that in this ditch, and in the pit (E 28, below), DDT has a prolonged effect on mosquito larvae holding their numbers down for at least four weeks. The effective kill, in spite of failure of oil to spread in the mat of algae, seems very remarkable. Can it be due to DDT dissolving in the water, in quantity sufficient to be larvicidal ? The point requires careful study in the laboratory.

A dose was also applied to a small isolated pit (E 28), similar to that to which mixture A was applied, and near it. The area was one sq. yard, depth six inches. There was extremely little vegetation in the water or on the bank. Mosquito larvae, *A. funestus* and a few Culicines : for four days before treatment, average counts were *An.* 10·5, *An. 1* 16, *Cul.* 4·5, Total 31. It was then treated with 0·5 cc. of the 5 per cent. DDT in dieseline and oleic acid, *i.e.*, five times the dose put on ditch C 13. The result was complete absence of larvae (except a very few *An. 1*) for five days, and thereafter a count which remained low for four weeks from date of treatment, when the pit dried up, as shown by the following average counts :—

	An.	*An. 1*	*Cul.*	*Total.*
Second week	4	19	3	26
Third week	2	13	10	25
Fourth week	3	10	11	24

These figures should be compared with those for the period before treatment, and seem to indicate a prolonged effect of DDT (in large dosage). There is not a complete control of larvae, but there is a great reduction in the proportion of *An.* Other pits and ditches in the immediate vicinity did not show a drop in numbers of larvae.

Similar work was carried out on a total of 13 ditches or pits, all stagnant and all breeding *A. funestus* 90 per cent., *coustani* 10 per cent. The results may be summarised thus :—

Dose cc. of 5 per cent. per sq. yd.	*No. of experiments.*	*Kill per cent.*	*Lasting, days.*
0·01	Two	100	1–2
0·02	Two	80–100	2–3
0·05	One	95	Not lasting.
0·10	Four	100	About four.
0·20	Three	100	7 or more.*
0·50	One	100	5 days complete. Up to 4 weeks partial (see E 28 above).

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* One place is the permanent ditch (Expt. 2) described above.

TABLE IV.

Results of applying DDT in Dieseline to *Tradescantia* Swamps : Larvae per ten Dips.

DAY	CONTROL SWAMP				TREATED SWAMP			
	An.	An. 1	Cul.	Total	An.	An. 1	Cul.	Total
1	15	18	0	33	11	21	0	32
4	8	12	0	20	6	12	1	19
5	13	23	1	37	7	8	0	15
6	16	12	0	28	1	5	0	6*
7	3	14	0	17	0	0	0	0
8	28	11	0	39	1	0	0	1
11	14	20	0	34	0	1	1	2
12	14	19	0	33	0	2	0	2
13	16	26	0	42	0	0	1	1
15	7	17	0	24	2	0	0	2
17	7	12	1	20	3	5	2	10
20	17	8	1	26	2	0	1	3
						(drying up)		

* Treated after larvae counted.

The *Tradescantia* swamp which had been treated with mixture A in August (Table II) came back to normal and was used for a second experiment six weeks later, see Table IV. The area and general state of the swamp and control swamp were as before, and the same amount of DDT was used as in the second application of mixture A to this swamp. That is to say, 6 gm. pure DDT dissolved in dieseline (with 0·25 per cent. oleic acid) were distributed by Maney hand sprayer. The experiment is not very convincing because the number of *An.* in the treated swamp was always low, even before the insecticide was applied. The results appear to be similar to those of the second experiment with mixture A.

4. *DDT in other Mineral Oils.*—A few experiments were performed with DDT dissolved in other mineral oils. The series had to be discontinued owing to drying up.

In kerosene in a single set of experiments on ditches, I obtained 90 to 100 per cent. kill of larvae (*A. gambiae*) at dosages down to 0·08 cc. of 5 per cent. of pure DDT per sq. yard. This figure is not as low as the lowest which gave a similar kill with dieseline. As the kerosene had a spreading pressure of only 16 dynes per centimetre its success is perhaps remarkable.

Similar tests were carried out with mixture C. The few experiments started were cut short by drought. The lowest dose tested was 0·10 cc. of mixture per sq. yard. In the only experiment at this dosage it killed 95 per cent. of larvae, and was still effective a week later when the ditch dried up. A dose of 0·40 cc./sq. yard on a shallow wall killed all larvae and was completely successful (save for a few instars) for ten days, and partially after that.

A tentative conclusion seems justifiable : Kerosene and mixture C are not much more or much less effective than the dieseline solution.

Discussion.

At the present moment much preliminary work on DDT as a larvicide has been done in several continents. It is only recorded in semi-permanent papers which have a limited and eclectic circulation. It seems therefore important to get facts on record, but impossible at present to enter into a full discussion of the subject.

The following rather isolated notes are, therefore, presented, mainly to provoke thought and further work. It has to be remembered that the work here described was rather "critical", in the sense that attention was focussed on doses so small as not to give complete kill: small variables, such as little topographical features in one length of ditch, may therefore have had a considerable effect.

(*a*) *Comparison of Mixture A (an emulsion) and Dieseline Solution.*—The text summarises a considerable number of experiments with the emulsion and solution in ditches, and the figures show that the dieseline solution is effective at very low doses (0·02 and 0·01 cc. of 5 per cent. pure DDT), and that the emulsion is not effective at 0·05 cc. The difference is probably not as great as these figures would seem to indicate, for there was some surface current in a number of the experiments in which mixture A was used. There is apparently a similar difference in lasting effect; for instance, the " pit on a cross drain " received a heavy dose of mixture A (0·5 cc.), which destroyed all larvae, the population recovering by day eleven and, indeed, exceeding what it has been before treatment. In contrast with this pit E 28, similar in size, and receiving the same dose, in dieseline, showed a partial control of *Anopheles funestus* for several weeks.

It seems then that the dieseline is effective at lower doses than mixture A, and that at higher doses the dieseline remains partially effective for a longer time. This result is unexpected, for by the time the emulsion has been put down on the water it consists of a number of minute lenses of non-volatile oil in which the DDT is in solution. One might, therefore, have expected an identical effect, or even that the emulsion would be superior, owing to its greater spreading pressure.

(*b*) *DDT probably Effective in Solution in Water.*—It will be remembered that in the roadside ditch (Expt. 2) the DDT in dieseline was dropped on floating mats of filamentous algae which evidently prevented its spread. None the less a fairly heavy treatment (0·2 cc.) killed all larvae. It seemed reasonable to think that the DDT had dissolved from the oil into the water in concentration sufficient to be larvicidal.

(*c*) *Prolonged but imperfect Control.*—In all the four tables, and in pit E 28, and the permanent ditch in Experiment 2, one sees that a fairly heavy dose of DDT (0·2 or 0·5 cc.) will have a complete larvicidal effect for some days, followed by a partial effect for as much as four weeks. This may occur either with emulsions or solutions, and is extremely difficult to understand.

One may call particular attention to E 28, because the conditions there appear simple. The pit was very small, shallow and almost free of vegetation. The dose of DDT in dieseline was heavy (0·5 cc.), and the volume sufficient to cover the area very thoroughly. All larvae were destroyed, but after five days some large larvae appeared (*i.e.* some were surviving for at least a few days), though the count remained for some weeks much lower than it had been before treatment. In such a case as this there are two points which are difficult to explain, the fact that the DDT has " disappeared ", and the fact that it has a prolonged effect, insufficient to kill all larvae. One has reason for thinking that the " disappearance " can hardly be due to evaporation or chemical change (effect of ultraviolet, hydrolysis); if the DDT has dissolved in the water that would not, we should suppose, render it ineffective as a larvicide, especially in so shallow a water. It seems possible that the insecticide may be stranded on the mud bank if minute waves are formed by wind, or that it is sorbed on the mud of bank or bottom of pool. In some waters, but not in E 28, the growth of grass and reeds or other " emerging " vegetation might carry DDT up and away from the water surface, or growing leaves, etc., might conceivably absorb the DDT in oil.

The above considerations would provide possible explanations of the disappearance of the DDT; its prolonged though imperfect effect remains a puzzle. In a long ditch full of algae and sedges (*e.g.* Expt. 2) one might have local " topographical " differences, due either to an original failure to make an even distribution or to strictly local differences in growth of grass, sorbtion on particular types of mud, etc. But this type of explanation cannot hold good for the small simple pit E 28. The phenomenon, therefore, remains one requiring further study.

(*d*) *Effect of DDT on Predators.*—In the case of the "pit on the cross drain" a heavy dose (0·5 cc.) of mixture A killed all the small fish, and a subsequent increase of *Anopheles* larvae was observed. In other experiments we never observed destruction of either fish or aquatic predatory larvae (Odonata, etc.), though no quantitative work was done. Moreover some places were subjected to prolonged observation; but no great increase of mosquito larvae, such as might follow destruction of predators, was observed. It is certainly important to bear the possibility in mind and discover whether it occurs in other types of water.

Summary.

(*a*) Small field experiments (not attempts at control) are described with DDT in emulsion and in solution in mineral oils, 5 per cent. pure DDT in each material. These were tested on mosquito larvae (mainly *A. funestus*) under conditions that provided good opportunities for repetition and measurement of dose per unit area. Considerable day to day fluctuations were observed in numbers of larvae obtained by dipping, before the insecticide was applied.

(*b*) Preliminary work showed that kerosene, or dieseline without DDT, were not larvicidal in doses up to 0·5 cc./sq. yard. The dose of oil that was harmful was not determined.

(*c*) It is clear that DDT, either in oil or as an emulsion, is a very effective larvicide, as is well known from work (mostly unpublished) in many parts of the world.

(*d*) One may compare the effectiveness of DDT as an emulsion (Mixture A) and in solution in dieseline, as follows :—

Dose	Mixture A		Dieseline	
cc. 5 per cent. pure DDT/sq. yd.	Immediate (kill per cent.)	Lasting (days)	Immediate (kill per cent.)	Lasting (days)
0·01			100	1–2
0·02	nil	nil	80–100	2–3
0·10	over 80	1–2	100	4
0·50	95–100	7–10	100	5 (several weeks partial)

It is clear that, under these rather precise conditions of testing, the dieseline solution is more effective than the emulsion both in the minimum amount required to kill, and in lasting effect.

(*e*) Field tests seem to indicate that DDT dissolves from oil into water, so as to make a larvicidal solution, at least when the water is shallow.

(*f*) Even if one puts down a relatively high dose (say 0·10 cc. of 5 per cent. DDT per sq. yard, at least ten times the quantity that will kill all larvae) the effect passes off in a few days, even on stagnant waters. It is not known what happens to the DDT, and difficult to know why it disappears.

(*g*) A heavy dose of DDT (0·50 cc. as above) gives a period of complete kill, followed by a period of partial irregular control. This was more often observed with solutions of DDT than with emulsions and might last as much as four weeks. No explanation of this irregular effect is put forward. It seems most difficult to understand how an insecticide, applied over an area of only a few square yards, can continue to kill some but not all larvae for a period of weeks.

(*h*) Except in one experiment, in which emulsion destroyed small fish, there was no evidence that creatures which prey on mosquito larvae were destroyed. There was no reason for thinking that after the population of mosquito larvae got back to normal it rose to exceptionally high figures (as it might have, had the predators been decimated).

NEW INJURIOUS CURCULIONIDAE (COL.) FROM TROPICAL AFRICA.

By Sir Guy A. K. MARSHALL, K.C.M.G., F.R.S.

BRACHYDERINAE.

Heterostylus aliberti, sp. n.

♂♀. Derm black, with uniform dense sandy-brown scaling above and opalescent scaling beneath.

Head short, not transversely impressed, the temples less than half as long as an eye; frons with the median stria partly obscured by scaling and with a few erect spatulate setae on each side; eyes strongly convex, highest behind the middle. *Rostrum* similar in the two sexes, a little longer than broad, about as wide at the genae as at the base, and with the sides slightly sinuate; dorsum with a high bare median carina that expands apically into a broad bare epistomal area, which is unevenly punctate and not marginate, the epistomal setae being rather sparse and narrow, the areas on each side of the carina densely squamose and obliquely impressed in the middle; mandibles less densely setose than usual and without scales; mentum with only a single row of setae along the apical margin. *Antennae* black, densely squamose throughout, scape straight, widening from base to apex; funicle with joints 1 and 2 equal, 3 as long as broad, 4–7 subequal and transverse; club with the basal joint pedunculate. *Prothorax* transverse (2 : 3), broadly rounded laterally in the basal half, widest at one-third from base, the basal angles rounded obtuse angles, not constricted apically, the base shallowly bisinuate with the median lobe short and broadly rounded; dorsum smooth, with dense overlapping striolate scales and short appressed spatulate setae, concealing the median stria, and with a large shallow impression in the basal angles. *Scutellum* with dense pale opalescent scales. *Elytra* narrowly constricted at base in ♂, the basal angles being right angles, but not in ♀, narrower than usual at the shoulders and subparallel to beyond middle, jointly acuminate at apex; the striae containing deep bare round punctures separated by scaling; the broad intervals almost flat, with dense scales similar to, but rather smaller than, those on the pronotum, with short irregular appressed brown setae; the suture obtusely raised at the top of the declivity, which is shallowly sinuate in lateral view. *Legs* with dense brown scales, the tarsi, the inner face of the femora, and the apices of the femora and tibiae usually pale opalescent green.

Length, 6–8 mm.; *breadth*, 2·7–3·5 mm.

IVORY COAST: Bingerville, 3♂ 4♀, vii. 1941 (*H. Alibert*).

The adults are recorded as attacking Kola plants.

This small species is distinguished by the unusual shape of the prothorax, the high carina and broad bare apical area on the rostrum, the absence of dense setae on the disk of the mentum, and the absence of scales on the mandibles.

CLEONINAE.

Lixus latro, sp. n.

♂♀. Derm black, shiny; head and rostrum with two broad stripes of dense grey setae; prothorax with dense grey setae except for three broad bare dorsal stripes, the outer ones sharply defined, the median one less definite; elytra with intervals 1–5 clothed with fairly dense grey setae, 6–8 bare and shiny, and the whole lateral margin with denser longer whitish setae; underside with dense whitish setae and numerous irregular bare spots.

Head globular, with fine close punctation; frons depressed on each side, with sparse larger punctures and a deep median fovea. *Rostrum* shorter than the pronotum (4 : 5), parallel-sided, not dilated at the apex, only slightly curved, closely and finely punctate dorsally and with scattered larger punctures, without any trace of a median carina, the lateral punctures much coarser and longitudinally confluent near the base. *Antennae* with joints 1 and 2 of the funicle equal, the rest transverse. *Prothorax* about as long as broad, subconical, widest at base, gently rounded laterally, not constricted at apex, the postocular lobes short and broadly rounded; dorsum with the three bare stripes coarsely and subconfluently punctate, the intervals closely punctulate, the median stripe somewhat narrower than the others and with a rather broad low abbreviated median carina, the middle of the base deeply depressed. *Scutellum* small, immersed. *Elytra* elongate, distinctly broader at the oblique shoulders than the prothorax, parallel for three-fourths of their length and separately produced into a long sharp process at the apex, without any posterior callus; the very shallow striae with a row of separated punctures, some of those in stria 1 larger than the others; intervals much broader than the striae and flat, 3 raised at the base into a short broad subgranalate costa, the scutellar area shallowly depressed. *Legs* with rather dense grey setae, sometimes with faint small dark spots.

Length, 10·5–13·0 mm.; *breadth*, 2·6–3·6 mm.

ERITREA: Asmara, 9♂ 5♀, vi. 1944 (*G. Jannone*).

Reported to do serious damage by boring in the stalks of cabbages.

Most nearly allied to the Mediterranean *L. anguinus*, L., a longer, narrower species with more elongate apical processes; the prothorax has an additional black stripe on the pleurae and interval 4 on the elytra is also black; the rostrum is more curved; the pronotum has no median carina; the elytra have a shallow constriction at the base and interval 3 has no basal elevation.

NANOPHYINAE.

Nanophyes croceus, sp. n.

♂♀. Derm uniform testaceous yellow, the elytral suture often slightly darker; eyes and tarsal claws black, third tarsal joint fuscous; evenly and rather thinly clothed with white setae, which are denser at the sides of the sternum.

Rostrum of ♂ gently curved, a little shorter than the head and pronotum, the antennae inserted slightly beyond the middle, the dorsal outline continuous with that of the head; dorsum with three smooth narrow carinae from base to antennae, the intervening sulci shallowly punctate, the apical area with four rows of punctures; rostrum of ♀ a little longer than the head and pronotum, the antennae inserted at or slightly behind the middle. *Antennae* with the funicle shorter than the scape and slightly longer than the club, joints 3–5 as long as broad, 4 not asymmetrical. *Prothorax* only half as long as its basal width, with the sides quite straight, sloping steeply forwards, the dorsal outline slightly convex. *Elytra* rather short, broadly ovate, widest at the very sloping shoulders, the striae shallow, the intervals flat, interval 8 without any row of granules at the base; the white setae rather stout, recumbent, with 2–3 rows on an interval. *Legs* with a very small black tooth on the femora and a minute one beyond it; tibiae with the apical fringe of setae black, hind pair without a mucro.

Length, 1·0–1·2 mm.; *breadth*, 0·6–0·7 mm.

SENEGAL: Diorbivol, 9♂ 6♀, 1944 (*Dr. J. Risbec*).

Recorded as feeding in the flowers of bananas.

This is the only entirely yellow species so far recorded from Tropical Africa.

ITHYPORINAE.

Leurostethus, gen. nov.

Head, with the frons broad, as wide as the base of the rostrum and wider than an eye. *Rostrum* shorter than the pronotum in both sexes, moderately curved, widening towards the base; scrobes oblique, passing beneath the base of the rostrum. *Antennae* short; scape widening from base to apex, squamose; funicle with joints 1 and 2 of equal length, but 1 thicker; club short, broadly ovate, with the sutures transverse. *Prothorax* transverse, truncate at the base, the postocular lobes well developed, the gular margin deeply sinuate. *Legs* with the femora clavate, rather broad and flat towards the base, without any external carina, the tooth comparatively small, the hind pair not exceeding the elytra; front coxae contiguous; tibiae bisinuate on the lower edge, the hind pair with the dorsal edge forming a uniform gentle curve, the corbels ascending dorsally. *Sternum* with no furrow on the prosternum; metasternum a little longer than a median coxa. *Venter* with ventrite 1 very short behind the coxae; the three median ventrites equal in ♀, 2 a little shorter in ♂.

Genotype: *Leurostethus raphiae*, sp. n.

This genus differs from the other ITHYPORINAE that have contiguous anterior coxae in its short hind femora, which do not extend beyond the elytra; in the lack of the strong curvature of the hind tibiae on their basal half; and in the unusually short antennal club and its transverse sutures. It may be placed next to *Ichniochetus*, Kolbe.

Leurostethus raphiae, sp. n.

♂♀. Derm piceous, with fairly dense brown scaling; elytra with a common round pale spot near the posterior declivity extending laterally to stria 2.

Head with large reticulate punctures, each containing one or two narrow scales, so that the interspaces are bare; frons flat. *Rostrum* of ♂ shorter than the pronotum (7 : 10), gradually narrowing from base to antennae (one-fourth from apex) then widening slightly, with dense shallow punctures throughout, and with five narrow sinuous carinae and rough scaling on the basal three-fourths; rostrum of ♀ a little longer, more rapidly narrowed from base to antennae (a little beyond the middle), the basal part as in ♂, the apical part red-brown, cylindrical, shiny, with sparse minute punctures. *Antennae* piceous; scape with rough suberect scaling; funicle not squamose, joints 3–7 transverse, 7 a little longer than the others. *Prothorax* transverse (13 : 16), strongly rounded laterally, widest behind middle, much more narrowed in front than behind; dorsum with reticulate punctation and a sharp median carina that reaches the apical margin but disappears on the basal third, each puncture containing a scale, these being narrower on the disk than at the sides, with the margins of the punctures showing through. *Scutellum* nearly rounded, with dense pale scales. *Elytra* suboblong, a little wider at the roundly rectangular shoulders than the prothorax, parallel to beyond middle, with a low obtuse posterior callus; the striae with separated punctures visible through the scaling and each with a short recumbent seta; the intervals somewhat convex, with numerous small irregular granules and a row of short suberect spatulate setae. *Legs* piceous, with dense brown scaling, the femora with a pale spot dorsally near apex, the tibiae with a pale band beyond middle; anterior pairs of femora with only a small blunt tooth; hind tibiae of ♂ broadly flattened on the apical half of the lower surface, the uncus transformed into a short broad obtuse spatula.

Length, 5·5–6·0 mm.; *breadth*, 2·5 mm.

IVORY COAST: Abidjan, 1♂, on fruit of *Raphia*, iv. 1943 (type); Bingerville, 3♂ 2♀, bred from *Raphia* seeds, iv. 1943 (*H. Alibert*).

The spatulate uncus on the hind tibiae of the ♂ is a most unusual character.

BARIDINAE.

Baris nigritula, sp. n.

♂♀. Derm rather dull black, entirely bare above, underside with a narrow pale scale in each puncture.

Head finely aciculate, with small isolated shallow punctures, separated from the rostrum by a very deep impression. *Rostrum* as long as the pronotum in both sexes, strongly curved, about as wide as high at the base, parallel-sided, gradually narrowing at apex in lateral view, coarsely and closely punctate throughout in ♂, less coarsely punctate on the apical half in ♀. *Antennae* black; funicle widening distally, joint 1 as long as 2–4, 2–7 transverse, 7 twice as broad as long and fitting closely to the club. *Prothorax* about as long as broad, parallel-sided from base to middle, then gradually narrowing with a curve to the broad apical constriction; dorsum slightly convex longitudinally, with coarse shallow subreticulate punctation, without any smooth median line. *Scutellum* round, shallowly punctate, uneven. *Elytra* oblong-ovate, broader at the shoulders than the prothorax and shallowly sinuate behind them, separately rounded at apex, with feeble subapical calli and no dorsal impressions; the striae deep and sharp, becoming deeper at apex, with shallow catenulate punctures; the intervals flat, with a single row of large shallow punctures, interval 9 forming a rugose ridge towards the apex and joining up with 7 and 3, 10 forming a rather lower narrower ridge. *Legs* black, with the uncus and claws testaceous, coarsely punctate, with a narrow whitish scale in each puncture. *Venter*: pygidium rugose, similar in the two sexes; apical margin of the last ventrite bisinuate in ♂ only.

Length, 2·5–3·0 mm.; *breadth*, 1·0–1·2 mm.

SENEGAL: Karlack, 1♀, x. 1940; Bambey, 9♂ 8♀, i. 1944 (*J. Risbec*).

Recorded as attacking cucurbits.

Most nearly allied to the South African *B. tetra*, Boh., which, however, has the prothorax widening rather rapidly from the constriction to the base; the elytra are proportionately broader, with the basal margins more arcuate and the humeral callus much more prominent.

FRUIT-PIERCING LEPIDOPTERA IN NIGERIA.

By F. D. Golding, M.A., F.R.E.S.

Damage to citrus fruits by Noctuid moths is known to occur at Ibadan and Agege (about 14 miles north of Lagos). The majority of the observations recorded in this paper were made on Moor Plantation, Ibadan, during the 1938 and 1939 seasons. Box (1942) describes the crop ripening, in the Gold Coast, between April and August as the Main crop, and that ripening between September and December as the Mid crop ; in Nigeria, the bulk of the citrus ripens during the latter period, which is known as the Main crop. In this paper the terms wet season and dry season crops are employed.

In most years since 1937 considerable damage has occurred to the wet season crop (principally to tangerines, sweet oranges and grapefruit) ; but, to date, the dry season crop has escaped attack. Prior to 1937, there were few mature citrus trees on Moor Plantation and the damage was negligible.

Species of fruit-piercing Lepidoptera.

Hargreaves (1936) has listed 46 species of fruit-piercing Noctuids in Sierra Leone ; Cotterell (1940) has recorded 27 species in the Gold Coast, whilst Box (1942) has added another 88 species to the Gold Coast list.

In 1938, the writer's efforts were almost entirely concentrated on devising a method of control, whilst the 1939 season was remarkable for the small number of species present. For these reasons the Nigerian list comprises only 24 species, five of which are not recorded in the Sierra Leone or Gold Coast lists.

Achaea boris, Gey.
†_A. catella_, Guen.
A. faber, Holl.
A. lienardi, Boisd.
A. mercatoria, F.
A. mormoides, Wlk.
Anomis leona, Schaus
*_Anua gonoptera_, Hmps.
*_Audea endophaea_, Hmps.
Caligatus angasi, Wing
*_Cyligramma limacina_, Guen.
C. simplex, Grünb., attacking bananas at Gombe, Northern Nigeria.
Dermaleipa parallelipipeda, Guen.
Heliophisma catocalina, Holl.
Lacera alope, Stoll
*_Lophotavia incivilis_, Wlk., attacking mangos.
Miniodes discolor, Guen.
Mocis undata, F.
*_Nagia natalensis_, Hmps., attacking mangos.
Othreis divitiosa, Wlk.
O. fullonia, Cl.
O. materna, L.
Sphingomorpha chlorea, Cram.

In addition, the Satyrid butterfly, _Melanitis leda ismene_, Cram., was once observed piercing a grapefruit on a tree.

Nearly all the 19 species of Noctuids known to attack citrus have also been observed piercing mangos.

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* =Not on Sierra Leone and Gold Coast lists.
† =Not observed piercing fruit in the other Colonies.

The following list shows the most important species in each of the five years for which records are available :—

1937. *Achaea lienardi*, Boisd.
1938. *A. lienardi.*
1939. *Othreis fullonia*, Cl.
1940. *A. lienardi*, *A. faber*, Holl.
1942. *A. lienardi*, *A. faber*, *O. fullonia.*

In some years *Achaea mormoides*, Wlk., *Sphingomorpha chlorea*, Cram., and *Anomis leona*, Schaus, have been moderately abundant.

Achaea lienardi is known to have been very abundant on Moor Plantation in three years between 1922 and 1936, and Pomeroy (1921) recorded this moth as a serious pest of mangos in 1920.

Phototropism.

Both *A. lienardi* and *A. faber* often occur at light in houses in large numbers. Observations on the occurrence of these moths in houses were made in 1938, 1939, 1940 and 1942 ; one or both species were abundant on the following dates :—1938, 6th, 7th, 8th and 12th April ; 1940, 17th, 21st, 22nd April, 15th May ; 1942, 1st and 2nd April. On the morning of 1st April, 1942, large numbers of *A. lienardi* and *A. faber* were seen feeding on a heap of dry season grapefruit, which had been placed in a pit for burial as they were no longer fit for eating ; no fruit remained on the trees. That night moths entered a house in large numbers from the north, the heap of citrus was about 100 yards to the north of the house. On the night of 2nd April a large scale invasion occurred in a house 360 yards to the south-east of the first house. On the morning of 2nd April very few moths were present in the grapefruit pit, and it seems probable that an extensive migration was taking place.

Larval Food-plants.

From January to May, 1939, an extensive search was made for *Achaea* larvae on Moor Plantation and in the country within a radius of about three miles from its boundaries. Not a single larva was found. On 24th March a search for larvae was made in the Olokemeji Forest Reserve, about 22 miles west of Moor Plantation ; *A. lienardi* larvae were found on *Bridelia ferruginea* and *Monodora tenuifolia* and *A. faber* larvae on *Celtis prantlii*. *Achaea* adults were unusually scarce at Ibadan in 1939 ; but as no larvae have been found there in years when adults were abundant it seems probable that migration occurs, although it may be very limited as regards the distance covered by the moths before their arrival on Moor Plantation. It is of interest to record that the annual migration of the butterfly, *Libythea labdaca*, Westw., was in progress on 2nd April, 1942 ; the flight was to the south-east, which is the most usual direction (sometimes it is to the south or south-west).

Fruits attacked by Moths.

In addition to sweet orange, tangerine, grapefruit and mango, *Achaea* has been seen attacking Pitanga Cherry (*Eugenia uniflora*), guava and tomato. On one occasion, *A. faber* adults were seen piercing the fruits of *Ficus anomani.*

In 1939, the only year in which *Achaea* was rare, the mango trees on Moor Plantation were unusually late in fruiting ; a few ripe fruits were seen between 22nd April and 17th May, but they were not abundant until the last week of May. Normally, ripe mangos are abundant in late March or early April—the time at which the mass infestation of *Achaea* begins. In 1939, practically no damage was done to citrus before 7th May, when *Othreis fullonia* began to appear in the orchards. The writer was informed by Mr. Cotterell that conditions were similar in the Gold Coast in 1939, *Achaea* spp. were almost entirely absent and the damage—less than usual—was being done by *Othreis.*

Time of Attack.

On dull days *Achaea* will pierce fruit up to about 10.30 a.m. On the night of 30th/31st May, 1939, observations were made continuously from 8 p.m. to dawn; moths were rare at that time, but the following data show that piercing continues throughout the night.

Time of attack.	*Fruit attacked.*	*Species.*
8.25 p.m.	Grapefruit	*Miniodes discolor, A. boris.*
8.35 p.m.	Orange	*A. mormoides.*
9.05 p.m.	Grapefruit	*O. fullonia.*
9.10 p.m.	Grapefruit	*O. fullonia.*
9.30 p.m.	Grapefruit	*Heliophisma catocalina.*
11.05 p.m.	Orange	*O. materna.*
11.15 p.m.	Grapefruit	*A. lienardi.*
11.45 p.m.	Grapefruit	*O. fullonia.*
12.00 p.m.	Grapefruit	*Anomis leona.*
2.00 a.m.	Grapefruit	*A. boris.*
4.02 a.m.	Grapefruit	*Cyligramma limacina.*
5.00 a.m.	Grapefruit	*O. fullonia, Achaea* sp.
5.10 a.m.	Grapefruit	*C. limacina.*

Food Preferences.

In the course of some poisoned bait experiments, described later in this paper, ripe fruits of the following types were suspended from nine sticks in two orchards—banana, grapefruit and mango. On the night of 17th May, 1938, counts were made of the number of moths (principally *Achaea* spp.) piercing the different types of fruit; 60 per cent. were on mangos, 28 per cent. on bananas and 12 per cent. on grapefruit. Other experiments showed that ripe mangos were more attractive than ripe sweet oranges.

Notes on the Infestations of 1938, 1939 and 1942.

(*a*) *1938.* Large numbers of *Achaea* (principally *lienardi*) appeared in late March and attacked mangos and the early-ripening fruit of a few orange trees. In the latter part of April and the first half of May very considerable damage was done to citrus; in the whole period of seven weeks (late March to mid-May) only 12 specimens of *Othreis* were seen.

(*b*) *1939.* During April, very little damage was done to citrus and *Achaea* spp. (especially *lienardi*) were rare. During May, *Othreis* spp. became moderately abundant, nightly counts between the 17th and 24th showed that *Othreis* spp. (principally *fullonia*) were about 2½ times as abundant as *Achaea* spp. Damage to citrus was far less extensive than in the 1938 season. The mango crop ripened in late May and appeared to attract some of the moths away from the citrus; in the preceding year many mangos were ripe in late March.

(*c*) *1942.* *Achaea lienardi, A. faber* and *Othreis fullonia* were abundant on mangos; the citrus crop was unusually small and suffered only moderate damage.

Control.

Gunn traps were found of little use; a few *Achaea* were trapped, but *Othreis* was never seen visiting the traps.

A series of experiments with poisoned fruits was carried out during the 1938 season. It was found that the most effective means of killing the moths was to use mangos that had been soaked for one hour in a 1¼ per cent. solution of sodium arsenite in water. Three or four segments were cut out of each mango, and a scalpel was passed horizontally through the pulp to enable the poison to penetrate. The poisoned mangos were suspended by means of pieces of twine attached to 1½-inch nails driven into the stones ; a metal punch was used to drive the head of the nail through the fruit. Both *Achaea* and *Sphingomorpha chlorea* were attracted in numbers to these baits, on one occasion between 150 and 180 moths were seen feeding on 15 mangos ; one of the 12 *Othreis* seen in 1938 was feeding on a poisoned mango. Moribund moths were found in the orchards ; but no satisfactory means could be devised of testing the lethal effect of the bait in the field. Consequently, moths were collected and placed in a series of cages containing different types of fruit poisoned in various ways, several cages containing unpoisoned fruit were used as controls. Twenty-one *Achaea* adults were placed in a cage, containing two mangos that had been soaked for one hour in a 1¼ per cent. sodium arsenite solution, at 11 p.m. on 5th May ; 15 hours later seven moths were dead ; after 20 hours thirteen moths were dead and after 33 hours sixteen moths were dead and the remaining five were moribund. In the control cage containing six *Achaea*, after 33 hours one moth was dead and the remaining five were lively.

The chief drawback to this method is that it is dependent on the phenological vagaries of the mango and citrus trees ; for instance, it could not have been used in the 1939 season as the mangos were not ripe until the end of May, by which time the bulk of the citrus trees were already bearing ripe fruit. To obviate this disadvantage mango juice was extracted from a large number of fruits and was preserved by means of potassium metabisulphite. In the next season, this juice was poisoned with sodium arsenite (1 per cent.) and placed in trays in the citrus orchards; the results were disappointing as few *Achaea* were attracted to it. The work was discontinued after the publication of Box's report in which he follows Cotterell in recommending prompt harvesting of the citrus crop as a control measure. Previously the writer had been sceptical of the value of this method for two reasons, firstly, Cotterell's results showed that, even with daily harvesting, there was a 39·1 to 71·8 per cent. loss of the potential crop and, secondly, the writer had seen *Achaea* piercing grapefruits that were about two months short of maturity. Box found that by prompt harvesting the losses of oranges were reduced from a potential 93 to 10·7 per cent. and of grapefruit from 98·5 to 23 per cent. This method is now used on Moor Plantation and in 1943, when fruit-piercing moths were very abundant, resulted in the saving of a considerable proportion of the crop. The main disadvantage is that it involves the disposal of the bulk of the crop in a short period ; but it is preferable to have a glut of citrus over a few weeks than to have practically no crop at all.

References.

Box, H. E. (1942). Citrus Moth Investigations. Report on investigations carried out from December, 1939, to August, 1941.—Gold Coast, Colon. Dev. Fund.

Cotterell, G. S. (1940). Citrus Fruit-piercing Moths—Summary of information and progress.—W. African agric. Conf., Nigeria. Pap. 3rd W. Afr. agric. Conf. Nigeria 1938 sect. Gold Coast, **1**, pp. 11–24.

Hargreaves, E. (1936). Fruit-piercing Lepidoptera in Sierra Leone.—Bull. ent. Res., **27**, pp. 589–605.

Pomeroy, A. W. J. (1921). Entomology.—Rep. agric. Dep. S. Nigeria, 1920–21.

STUDIES ON THE BREEDING PLACES AND CONTROL OF *ANOPHELES GAMBIAE* AND *A. GAMBIAE* VAR. *MELAS* IN COASTAL DISTRICTS OF SIERRA LEONE.

By R. C. Muirhead Thomson, D.Sc.

(Pls. I—XIII.)

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Introduction.

The investigation described in this report was made possible by a grant under the Colonial Development and Welfare Act of 1940, and was carried out directly under the control of Dr. A. G. H. Smart, C.M.G., M.B.E., Medical Adviser to the Secretary of State for the Colonies.

I arrived in Freetown at the beginning of July, 1942, and left at the end of April, 1944, most of the time being spent in and around Freetown Estuary.

The work was greatly facilitated, and in some places only made possible, by the co-operation and assistance of various people.

The Director of Medical Services, Dr. Lightbody, put at my disposal a suitable room in the Medical Department which was used as a laboratory throughout the tour, and also provided me with an African laboratory and field assistant who had a thorough training in sleeping sickness work, and who later showed an equal aptitude for mosquito work. In those and in many other ways the Civil Health Department has been of the greatest possible assistance.

I am greatly indebted to Prof. Buxton for his constant help and guidance ; his unfailing interest in the various problems has provided a constant stimulus.

I was also very fortunate in that most of my tour coincided with that of Lt.-Col. R. F. Tredre, O.C. No. 5 Malaria Field Laboratory, and Area Malariologist for Sierra Leone. We worked together in close harmony in all aspects of research and malaria control, and his keen appreciation of research findings played a big part in turning these to practical account with the least possible delay.

The rapid survey of *melas* breeding places in Freetown estuary was only made possible by the help of the R.A.F. and the Fleet Air Arm, in particular to the P.M.O. Group Captain Corbet, and his successor Group Captain Kirkpatrick. The photographic section of the R.A.F. under Flying Officer Fry and later Flight Lieutenant Webb spent a great deal of time and attention on selecting and enlarging special negatives of mangrove areas, and it is entirely due to them and their staff that we now possess such a perfect series of aerial photographs of *melas* breeding places.

Among non-medical officials I am particularly grateful to Mr. E. I. Nesbitt, Senior Agricultural Officer, for his hospitality at the Rice Experimental Station and for the various ways in which he assisted the study of Anopheline breeding in relation to rice cultivation.

I am also indebted to Mr. H. Macluskie, Agricultural Officer, for advice and demonstration on bunding and empoldering, and it was his reclamation scheme at Maswari which provided the first working model on which control of *melas* was later modelled.

I am also grateful to Mr. Macgregor, Conservator of Forests, for his advice about *Avicennia* and mangroves in general, and also for his keen appreciation of mosquito control problems and their relation to rural development.

Dr. V. J. Chapman of the Botany School, Cambridge, provided valuable information about mangroves, and was kind enough to let me have the loan of unpublished material on the ecology of *Avicennia* and other mangroves.

To Mr. P. Slater, Sanitary Superintendent, I am indebted for placing at my disposal in the early stages of the investigation his thorough knowledge of local conditions in and around Freetown, and also for his assistance in carrying out the experiments on the effect of flushing.

The Identity of *Anopheles gambiae* and *A. gambiae* var. *melas*.

The name of *A. gambiae* var. *melas* was first given to forms of *gambiae* showing extreme dark pigmentation and bred from larvae found in brackish water in Gambia (Evans, 1938). The association of this dark variety with coastal regions has been recognised for some time, and Evans (1931), describing Barber's experiments, suggested that the race of *gambiae* which is capable of developing in brackish water becomes much darker when reared in brackish than in fresh water ; she also pointed out that this race can develop in normal time in water of salinity at least equal to 46 per cent. sea water.

In its most distinct form, *A. gambiae* var. *melas* differs from typical *gambiae* in having a black band dividing the last pale segment of the palps. In some of the dark forms, however, this 4-banded condition was absent, so that the systematic position of this *melas* remained uncertain.

Ribbands (1944a), working in Sierra Leone, found this variety abundant at Aberdeen, a village beside a mangrove creek at the mouth of the Freetown estuary. He showed that the extra dark band on the palp of var. *melas* is not a diagnostic feature and that it bears no relation to the salinity of the larval breeding places. When families of *melas* were subdivided and reared in varying concentrations of sea water, the proportion of specimens with the extra dark band was the same in fresh water as in 100 per cent. sea water. He showed that *melas* could be differentiated physiologically from *gambiae* by tests on the larvae ; transference to 60 per cent. sea water is fatal to *gambiae* larvae, but has no harmful effect on larvae of *melas*. With regard to the adults he found that on the average one-third of *melas* had 4-banded palps, the other two-thirds being 3-banded, and indistinguishable from typical *gambiae*.

Shortly after the beginning of this present investigation it was found that the eggs of *melas* are decidedly different from those of typical *gambiae*. In areas where the *melas* form of adult had never been found, all the eggs laid by females were of the typical form. When 4-banded *melas* were found, *melas* eggs were laid by all the 4-banded adults, as well as by many of the 3-banded ones. By this means the identity of *melas* was established, and it was now possible to separate typical *gambiae* from the hitherto indistinguishable 3-banded *melas*.

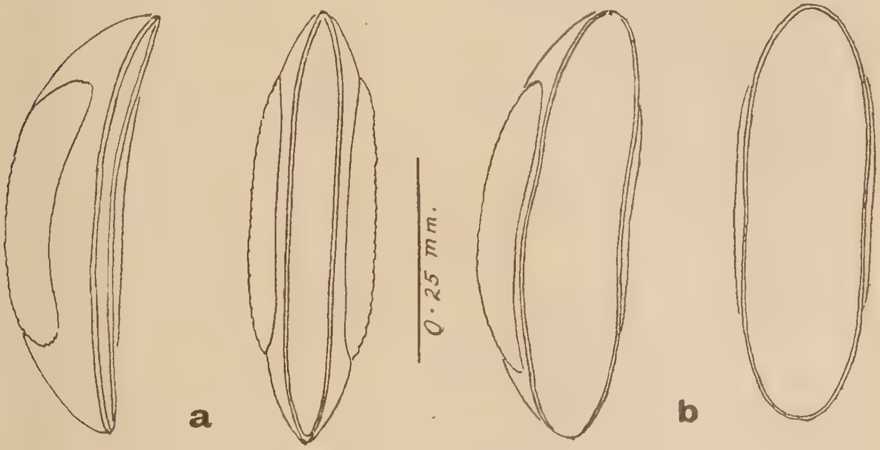


FIG. 1. Eggs of a, *Anopheles gambiae* ; b, *A. melas*.

The egg differences are as follows :

Typical *gambiae* (fig. 1, a). Upper surface narrow, with distinct space between frill and float, this space being sufficiently wide to show the polygonal markings of the chorion.

melas (fig. 1, b). Upper surface broad, with space between frill and float so narrow that they appear to be in actual contact.

The appearance of the two eggs is so distinctive that the characters given above are sufficient for differentiation. Of many thousands of eggs examined, no transitional forms have been seen, and on this character alone it appears that we are dealing with two distinct species. We can now distinguish adults of the two species by the following characters :

Palps 4-banded	4-banded *melas*	*melas* egg.
Palps 3-banded	3-banded *melas*	
	typical *gambiae*	type egg.

The 4-banded form of palp has been known to occur as a rarity in typical *gambiae*, but has not been found in Freetown estuary and is evidently sufficiently rare not to upset the general scheme above.

Recently Ribbands (1944a) has found that larvae of typical *gambiae* and of *melas* can be distinguished by their pectens. In *gambiae*-type the pecten has 4–5 long slender teeth without spicules, usually alternating with three groups of 3–6 short teeth with spicules. In *melas* the pecten has no markedly longer teeth, and all teeth are spiculate.

There still remains to be found some structural feature which will enable 3-banded *melas*, which can't or won't lay eggs, to be distinguished from typical *gambiae*, and at the same time render unnecessary the present rather laborious method of getting each wild-caught female to lay eggs in order to establish its identity.

The term " *A. gambiae* var. *melas* " is only used in the title of this paper as it was the accepted name for what up till very recently was regarded as a variety of typical *gambiae*. Throughout the rest of this report it will be referred to simply as *melas*.

The Distribution of *A. gambiae* Type and *A. melas* Eggs in Fresh Water Breeding Places.

With the discovery of the egg characters, it was now possible to find out to what extent *melas* makes use of fresh water pools. Although *melas* was known to be associated with coastal areas and brackish swamps, it was still possible that in those areas breeding took place in fresh water as well. Furthermore Blacklock & Wilson (1941) had recorded breeding 4-banded forms from fresh water pools near the sea in Freetown.

Rainy Season. A survey of breeding places by egg collections was made during the rainy season, during August, September and October, 1942. The three main areas selected were as follows :—

> Aberdeen Creek. This area, which will be described in more detail later, lies at the mouth of the Freetown estuary. Ribbands had found high catches of *melas* here, and breeding in a salty swamp outside the mangroves. In fresh water pools just above high spring tide mark there was continuous breeding of *gambiae*-type during the rains. From these fresh water pools and puddles the following eggs were collected, in 16 visits, over a period of 6 weeks : *A. gambiae*, 1057 ; *A. melas*, 0.
>
> Wellington. This village, 8 miles east of Freetown, marks the beginning of the great mangrove belt extending eastwards along the south side of the estuary. In this district high catches of *melas* adults were found in several villages, but the breeding places of *melas* were not known at that time. Eggs collected in fresh water pools just above high spring tide mark were, *A. gambiae*, 311 ; *A. melas*, 0, in five collections extending over 5 weeks.
>
> Kline Point, Freetown. At this eastern end of Freetown, on high ground 30–40 yards from the sea, dense breeding of *A. gambiae* was found within quite a small area. Large numbers of full grown larvae and pupae being found in numerous shallow rain-filled pools and puddles. In five collections extending over 3 weeks in August and September, the following eggs were found : *A. gambiae*, 237 ; *A. melas*, 17.

From all these figures it appears that *A. melas*, even in areas in which it is very abundant, only makes use of fresh water to a negligible extent during the rains. Both at Aberdeen and Wellington extensive breeding grounds of *melas* were later discovered in the mangroves, and yet in both those places not a single *melas* egg was recovered from fresh water where *A. gambiae*-type was breeding.

At Kline Point 3–4 *melas* eggs were found at each collection, and out of 61 females bred from larvae found in these pools, two were 4-banded *melas*. At this place there are only small patches of mangrove, and these are unsuitable for *melas*. This kind of breeding place is rather like that found at Coaling Company, further along the same water front, by Blacklock & Wilson (1941), and it is likely that a few breeding places like this scattered throughout the town would account for the appearance of odd *melas* adults in houses, during the rains. This low breeding probably results from the occasional *melas* being blown into Freetown from the mangrove areas round the estuary.

In collecting eggs a white enamelled scoop or bowl was used to skim the surface of the water. The eggs floating on the surface of the bowl were picked up with the film of water on a wire loop and transferred to damp blotting paper in a numbered tube. The identification of eggs was carried out under a binocular microscope in the laboratory. Occasionally eggs were so abundant that they were picked up with the wire loop directly from the surface of the pool.

Dry Weather. In the dry weather, as will be described later, the normal brackish breeding places of *melas* become more and more unsuitable, until by March breeding is at a very low ebb. At that time, however, fresh water pools are still abundant along the edges of streams, in stream beds, and in irrigated sweet potato plots.

In streams and rivers in which *A. gambiae*-type was found breeding in the dry weather, egg collections were made between January and April. In 16 collections from three streams in *melas* areas the following eggs were recovered : *A. gambiae,* 582 ; *A. melas,* 0.

Of these eggs, 374 were taken in 7 collections from the Rekupa Stream at Wellington.

Collections in fresh water pools and puddles among sweet potato mounds just above the mangroves at Wellington yielded the following : *A. gambiae,* 430 ; *A. melas,* 13.

These figures show that there is very little tendency for *melas* to make use of fresh water pools outside the mangrove zone, even at a time of the year when the normal breeding grounds are quite dry and unsuitable.

Breeding Places of *A. melas.*

The work of Ribbands at the beginning of the war showed that in Aberdeen village, at the mouth of the Freetown estuary, there was a high proportion of *melas* in the adult catches ; and a breeding ground was found in a boggy area of sedge and sea grass outside the mangrove zone but flooded by sea water at high spring tides. Although prolific breeding was found over an area of about 100 yards square, no larvae were ever found in the belt of mangrove between this boggy ground and the creek.

For a long time this was regarded as a typical breeding place, and as a result a great deal of time was spent exploring miles of shore line in a search for similar types of ground, with negative results. The fact that the mangrove beside the breeding ground at Aberdeen was consistently negative for larvae discouraged careful search elsewhere in the mangrove zone. At this stage all the mangrove appeared to be of a uniform type --*Rhizophora*—and little attention was paid to the possibility of other species occurring. Finally, after about four months of fruitless search, extensive breeding was found in that part of the mangrove belt at Aberdeen where the mangrove was scattered over flat ground, and appeared to differ from the usual *Rhizophora.* This new mangrove was *Avicennia,* later shown to be by far the most important type of breeding ground for *melas* in Freetown estuary.

Description of Mangrove Swamps and Intertidal Zone.

In order to understand the peculiar distribution of *melas* breeding places, a brief description of the mangrove swamps will be necessary.

The intertidal zone, between low tide mark and high spring tide mark, is characterised in estuarine areas by great stretches of mangrove, of which there are two different kinds in West Africa. By far the most common is the Red Mangrove, *Rhizophora racemosa* (Pl. I, figs. 1–6), which has aerial stilt roots and viviparous seeds. It may occur in all parts of the intertidal zone, and varies in size from small stunted bushes on sandy soil to large trees with the main stem raised 10–20 feet above the mud by the stilt roots. The largest trees are found in the outer mangrove fringe and lining the numerous creeks. Most of the *Rhizophora* zone is flooded twice every 24 hours by the high tide.

Less common is the Black Mangrove, *Avicennia nitida* (Pl. II, figs. 2–5), which in appearance is much like an apple tree ; it has no stilt roots but the ground round it is covered with a stubble of asparagus-like stalks—pneumatophores—growing up from the shallow but extensive root system. The trees are well spaced and of more uniform size. They may occur as isolated trees or a narrow fringe along the upper edge of the *Rhizophora*, or they may occur as pure stands on very flat intertidal areas only covered by the high spring tides.

It is necessary to distinguish between these two mangroves because dense breeding of *melas* is mostly confined to large stretches of orchards of *Avicennia*, while *Rhizophora*, on the other hand, is almost entirely harmless.

Isolated *Avicennia* trees or even the narrow fringe along the upper edge of the *Rhizophora* zone are not important; it is only when the *Avicennia* occurs in characteristic orchards, which may vary in size from 2–3 acres to 50 acres or more, that dense breeding is likely to occur. As will be seen later, the *Avicennia* orchards are important, not because of the mangrove trees themselves, but because of the type of flat, badly-drained, peaty soil on which they grow.

The form and distribution of the mangroves varies in different places (fig. 2), but the following are the main types :—

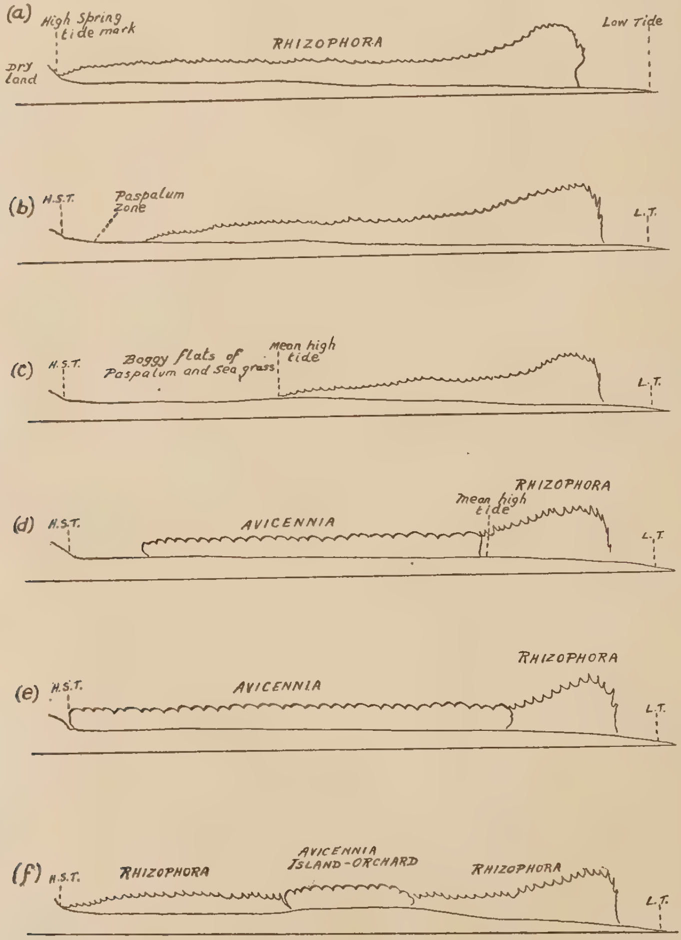

(a)
High Spring tide mark
RHIZOPHORA
Low Tide
Dry land
(b)
H.S.T.
Paspalum zone
L.T.
(c)
H.S.T.
Boggy flats of Paspalum and Sea grass
Mean high tide
L.T.
(d)
H.S.T.
AVICENNIA
RHIZOPHORA
Mean high tide
L.T.
(e)
H.S.T.
AVICENNIA
RHIZOPHORA
L.T.
(f)
H.S.T.
RHIZOPHORA
AVICENNIA ISLAND-ORCHARD
RHIZOPHORA
L.T.

FIG. 2. Sections of mangrove swamps from dry land to sea showing different arrangements of *Rhizophora* and *Avicennia*.

(*a*) In many places *Rhizophora* extends from a little above low-tide mark right to the highest spring tide limit along the dry land (fig. 2, *a*). This condition is found along most of the great mangrove belt from Wellington to Jui. *Melas* has never been found breeding in such places.

(*b*) Perhaps the most common condition differs from the first in that there is a zone of sea grass or *Paspalum* between the upper edge of the *Rhizophora* and the high spring tide mark (fig. 2, *b*). The sea-grass zone varies considerably in width, usually about 40–50 feet, and is sloping, firm, and well drained. It is seen at its best round the Hastings, Jui, and Fakai peninsulas south of the Bunce River as it flows into the estuary, and also along the entire east side of Aberdeen Creek. This type is almost completely free from *melas*. Where a great deal of seepage water comes off the land, patches of sedges replace the *Paspalum* (Pl. I, fig. 4).

(*c*) In a few places the sea-grass area described above may be flat, badly drained, and peaty. This is possibly ground on which *Avicennia* formerly grew as conditions are much the same. Breeding places of this type are unusual, and the only two known are at Aberdeen, and are probably maintained by the large *Avicennia* orchard nearby. The first breeding ground described by Ribbands was of this type, and within a small area breeding may be dense although it never extends into the *Rhizophora* beyond the extreme upper limit (fig. 2, *c*, & Pl. II, fig. 1).

(*d*) Where *Avicennia* orchards occur, it is usually in the form shown in fig. 2, *d* & *e*. At its outer margin the orchard is always protected from the sea by a belt of *Rhizophora* of varying depth. At its upper margin the *Avicennia* may extend right up to the high spring tide mark, where there is a sharp transition to the thick bush of the dry land (fig. 2, *e*, & Pl. II, fig. 5), or there may be a flat area of sea grass or *Paspalum*, up to 40–50 yards wide, between the upper edge of the *Avicennia* and the high spring tide limit (fig. 2, *d*, Pl. II, fig. 6, Pl. III, fig. 2). In the main breeding places larvae may be distributed right through the orchard, extending to its outer limit a few yards only into the *Rhizophora*. At the upper edge breeding usually extends over the open grassy shore if there is one. When the *Avicennia* trees are cut down or die off, the cleared ground becomes covered with a thick growth of *Paspalum*, in which *melas* continues to breed. It seems fairly certain that the *Paspalum* swamps found in other parts of West Africa were originally formed from *Avicennia* orchards in this way.

(*e*) Most of the *Avicennia* orchards in Sierra Leone are of the type described in the preceding paragraph, with the flat orchard in contact with the land along its upper edge. But in some large expanses of mangrove we sometimes find small *Avicennia* orchards separated from the land, and completely surrounded by *Rhizophora*. These "island orchards" can only be reached through a dense tangle of *Rhizophora*. While this surrounding *Rhizophora* is flooded at every high tide, the island orchard like other *Avicennia* orchards is only flooded by the high spring tides, and is therefore at certain stages of the tide virtually an island (fig. 2, *f*).

Along the south side of the Freetown estuary there are several of these small island orchards in all of which *melas* has been found breeding, but only to a very limited extent. They will be described more fully later (Pl. X, figs. 1–2).

As has been described above, the close association of *melas* with *Avicennia* is not necessarily due to that mangrove itself, but rather to the conditions under which it grows in pure stands or orchards. Most *Avicennia* orchards grow on fairly firm peaty soil into which the foot seldom sinks more than a few inches. The stubble of pneumatophores which covers the ground and is particularly dense under the largest trees, serves to trap all the dead leaves and produces a top-dressing of slowly decaying vegetable matter. As the areas are flat and badly drained it seems fairly certain that there is a continual deposition of silt and débris, particularly in parts of the orchards where tidal currents meet and produce a stagnant backwater. In some orchards the inner part nearest the land has peaty soil, while the outer part becomes more and more sandy. *Melas* is seldom found in these sandy patches.

Rhizophora, on the other hand, can grow on widely different types of soil such as sandy soil, gravelly soil, and firm smooth fibrous peat. The high *Rhizophora* which forms the outer belt of the mangroves and lines the creeks is rooted in a soft black mud through which progress on foot is almost impossible. The transition from one type of soil to another is often very sharply marked.

As will be described in more detail later, the salinity conditions of surface pools in the *Avicennia* orchards vary considerably, some of the pools near the land being quite fresh on occasions. Egg collections show, however, that in these swamps we are dealing almost entirely with *melas*. In 42 collections over 2,000 eggs have been taken from the two orchards nearest Freetown, and identified as *A. melas* 1,998, *A. gambiae*-type, 16 (on six occasions).

TABLE I.

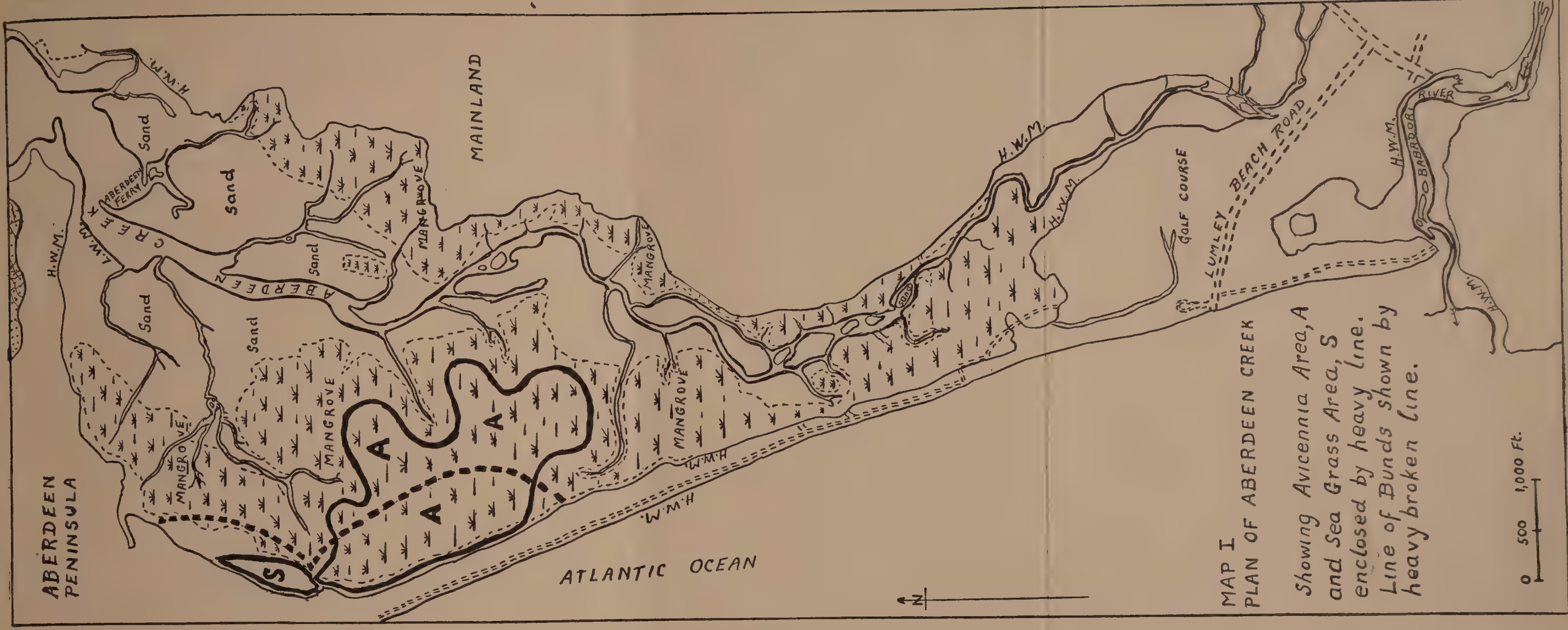
Different types of tides in Freetown as exemplified by high tides (in feet) of October, 1942, February, 1943 and August, 1943.

Date	October, 1942		February, 1943		August, 1943	
	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.
1	7·8	7·9	8·3	8·6	9·5	8·9
2	7·3	—	8·6	9·3	9·6	8·9
3	7·6	7·1	9·1	10·0	9·5	8·9
4	7·6	7·3	9·6	10·5	9·4	8·7
5	7·8	7·8	9·8	10·7	9·3	8·6
6	8·5	8·4	9·9	10·7	9·0	8·4
7	9·1	9·0	9·7	10·5	8·8	8·2
8	9·6	9·6	9·4	9·9	—	8·5
9	10·1	10·0	8·9	9·3	8·0	8·3
10	10·3	10·3	—	8·4	7·9	8·2
11	10·5	10·4	8·5	7·9	8·1	8·4
12	10·4	10·3	7·8	7·4	8·6	8·8
13	10·1	9·9	7·3	7·3	9·3	9·3
14	9·5	9·5	7·0	7·4	10·0	9·8
15	8·9	8·9	7·0	7·9	10·6	10·2
16	8·3	—	7·5	8·4	10·9	10·4
17	8·5	7·9	7·9	8·7	11·1	10·4
18	8·4	7·9	8·3	9·0	10·9	10·1
19	8·6	8·4	8·5	9·4	10·5	9·6
20	9·2	9·1	8·7	9·5	9·8	9·1
21	9·7	9·6	8·9	9·5	—	9·1
22	10·0	10·0	8·9	9·5	8·5	8·4
23	10·1	10·2	8·9	9·4	8·0	7·8
24	10·2	10·2	8·6	9·1	7·8	7·5
25	9·9	10·1	8·5	8·8	7·8	7·5
26	9·6	9·9	8·1	—	8·1	7·9
27	9·3	9·5	8·4	7·7	8·6	8·3
28	8·8	9·1	7·9	7·6	9·0	8·6
29	8·3	8·6			9·3	8·9
30	7·7	8·2			9·5	9·2
31	7·3	7·8			9·6	9·3

The Influence of Tides on Breeding.

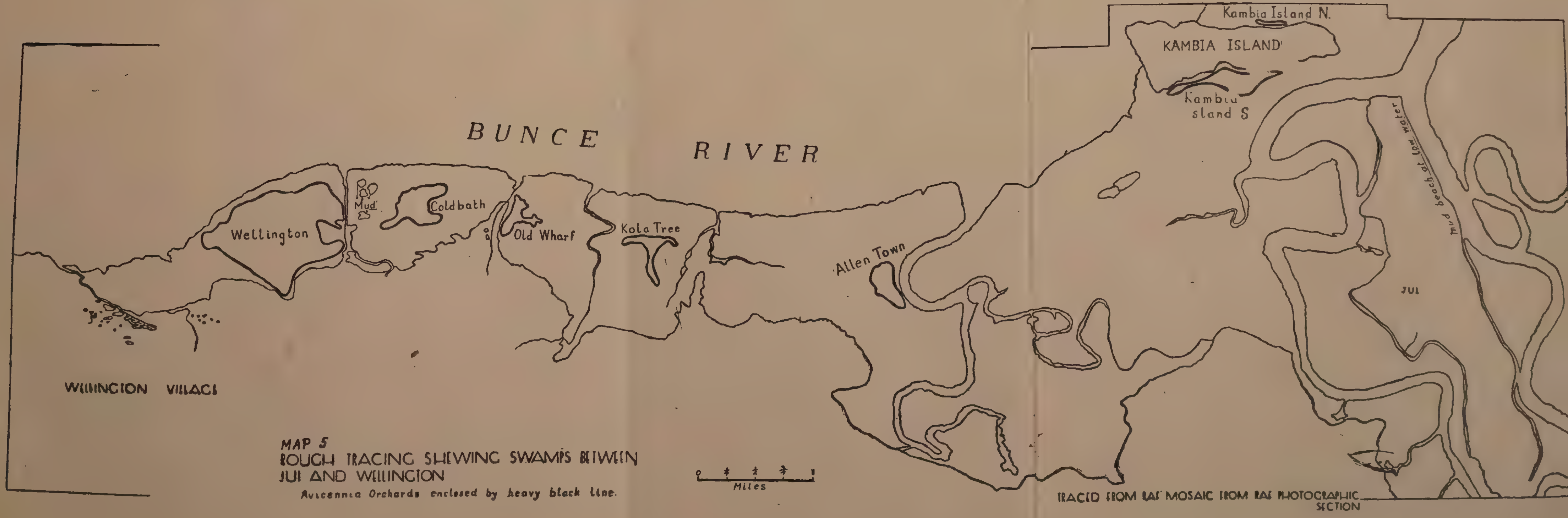
General Description of Tidal Conditions.

In the mangrove swamps the conditions of *melas* breeding are mainly controlled by the tides, and a fuller knowledge of these tides is therefore essential before proceeding further.


MAINLAND
ABERDEEN PENINSULA
ABERDEEN CREEK
ABERDEEN FERRY
Sand
MANGROVE
H.W.M.
L.W.M.
A
S
ATLANTIC OCEAN
GOLF COURSE
LUMLEY BEACH ROAD
BABADORI RIVER
N
0 500 1,000 Ft.

MAP I
PLAN OF ABERDEEN CREEK

Showing Avicennia Area, A and Sea Grass Area, S enclosed by heavy line.
Line of Bunds shown by heavy broken line.


BUNCE RIVER
Kambia Island N.
KAMBIA ISLAND
Kambia Island S
Wellington
Mud
Coldbath
Old Wharf
Kola Tree
Allen Town
JUI
mud beach at low water
WELLINGTON VILLAGE
0 ¼ ½ ¾ 1
Miles

MAP 5
ROUGH TRACING SHEWING SWAMPS BETWEEN JUI AND WELLINGTON
Avicennia Orchards enclosed by heavy black line.

TRACED FROM RAF MOSAIC FROM RAF PHOTOGRAPHIC SECTION

Apart from the *Avicennia*, most of the mangrove zone is flooded by the high tide twice every 24 hours. At low tide all the mangrove is left uncovered, and there is a stretch of muddy or sandy beach exposed between the outer mangrove edge and the low tide mark (fig. 2 & Pl. IX, fig. 1).

As the high tide mark is not constant, varying with the different phases of the moon, it follows that the degree of flooding in the mangroves varies likewise. At the period of full moon and again at the change of the moon occur the spring tides, when there is a maximum range—up to 15 feet—between high tide and low tide, and a maximum degree of flooding in the mangroves. The high spring tides themselves are variable and reach a greater height at the change of the moon than at full moon. The highest spring tides early in the month may be as much as 1½ feet higher or lower than the highest spring tides later in the month. Conditions vary from month to month but the three main types are shown in Table I & fig. 3, and are as follows :—

(*a*) In the first type (fig. 3), *e.g.*, October, 1942, the two spring-tide periods in the month are of equal altitude, the highest tides being over 10 feet in both cases. Most *Avicennia* orchards are completely flooded by tides higher than 9·6 to 9·8 feet, so that twice in this particular month the high spring tides flooded the *Avicennia* zone once every 12 hours for 4 or 5 days.

In this case also the morning high spring tides are about as high as the evening ones.

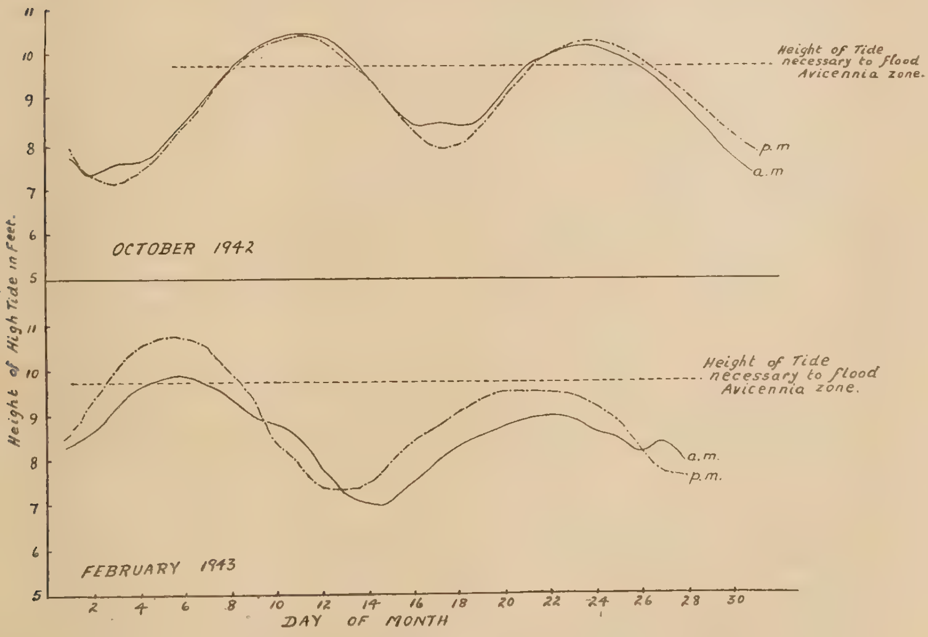


FIG. 3. Different types of high tide occurring in Freetown estuary.

(*b*) In the second example (fig. 3), February, 1943, the first series of high spring tides are over 1 foot higher than the second series in the month. The first spring tides flood the *Avicennia* orchard once every 12 hours for about 6 days. The second series, however, only reach the outer fringe of the *Avicennia*, and the orchard is therefore left untouched by the tide for over three weeks at a time. When this happens in the dry weather, when the water table is low and rainfall scanty, the whole *Avicennia* area becomes baked dry in this interval, and breeding of *melas* is completely eliminated.

With this type the evening high tides are much higher than the morning ones.

(*c*) This type, exemplified by August, 1943, resembles the previous type in having one series of spring tides much higher than the other, the largest peak in this case being the second one. The morning high tides are here higher than the evening ones. During the period of the investigation, this type of tide occurred in the rainy season, and produced the highest spring tides of the year—11·2 feet—flooding most *Avicennia* orchards to a depth of nearly 2 feet.

The first series of spring tides fails to flood the *Avicennia*, but this has little controlling influence on *melas* during these months because much of the *Avicennia* remains flooded with rain and seepage water, and never dries up completely as in the dry weather.

During the progress of the month the high tides are about an hour later each day, but the highest spring tides nearly always occur between 6 a.m. and 9 a.m. in the morning, and again between 6 p.m. and 9 p.m. in the evening.

Influence of Tides on Oviposition and on Periodicity of Breeding.

Detailed observations on conditions affecting breeding of *melas* were made in three different breeding grounds which differ in character although subject to almost identical tidal influence.

Aberdeen (*Avicennia* area). This area conforms to Type d (fig. 2, *d*). The mainland here is a low sand dune separating one side of the creek from the sea, and except during heavy showers very little water comes off this land into the mangrove. A plan of the area is shown in Map 1. Between the upper limit of the *Avicennia* and the high spring tide mark is a narrow grassy shore (Pl. III, fig. 2). From this the flat zone of *Avicennia* extends outward for about half a mile. Dense breeding may occur on the narrow open shore and through the whole *Avicennia* zone as far as the upper fringe of the *Rhizophora* (fig. 2, *d*). After all this area has been flooded by the spring tides for 4 or 5 days, the tides recede and the surface pools are left undisturbed till the next spring tides.

When this area was first discovered in October, at the end of the rainy season, larvae were abundant in the shore pools and in the upper half of the *Avicennia*. As the dry weather approaches, the shore pools dry up quickly, or are not reached by the high tides, and breeding is then confined to the numerous pools inside the *Avicennia*. Later the outer half of the *Avicennia* becomes the main breeding ground, larvae being common 500–600 yards from the land, until finally the whole area dries up too quickly for breeding to continue.

In all these pools the greatest number of full-grown larvae and pupae were found about a week after the first high spring tide. In this particular month both series of spring tides flooded the breeding ground (fig. 3) and there was therefore a peak production of pupae, and presumably of adults, for two or three days each fortnight. At the time when full-grown larvae and pupae are most abundant, and the pools are not reached by the tide, very few eggs and young larvae can be found in the breeding area. Although conditions appear ideal, there is evidently not much egg-laying at this time.

If we trace this sharp production of pupae, and therefore adults, back to its logical conclusion, it appears that there must be a great production of eggs and young larvae about 6–7 days before this peak, which brings us back to the very beginning of the high spring tides. As has been described above, the high spring tides always occur between about 6–9 in the morning and again at the same time in the evening. At the beginning of the high spring tide period, therefore, after the breeding area had been flooded for the first time, egg collections were made in pools on the shore and along the edge of the *Avicennia* very early in the morning before the high tide again flooded the area. By digging small pits and collecting the surface water from a big area many eggs of *melas* were found. These eggs had been laid in pools left by the high tide of the previous evening, and shortly after the collections were made the pools were again covered to the depth of about one foot by the early morning high tide. At high tide egg collections were continued in the open water flooding the shore region, and more eggs were found over a considerable length of *Avicennia* edge, suggesting the presence of very large numbers of eggs in the aggregate. About an hour later, after the tide had receded, it was extremely difficult to find any eggs. These observations were continued through two spring-tide periods in October and November, 1942, and the results are shown in Table II and graphically in fig. 4.

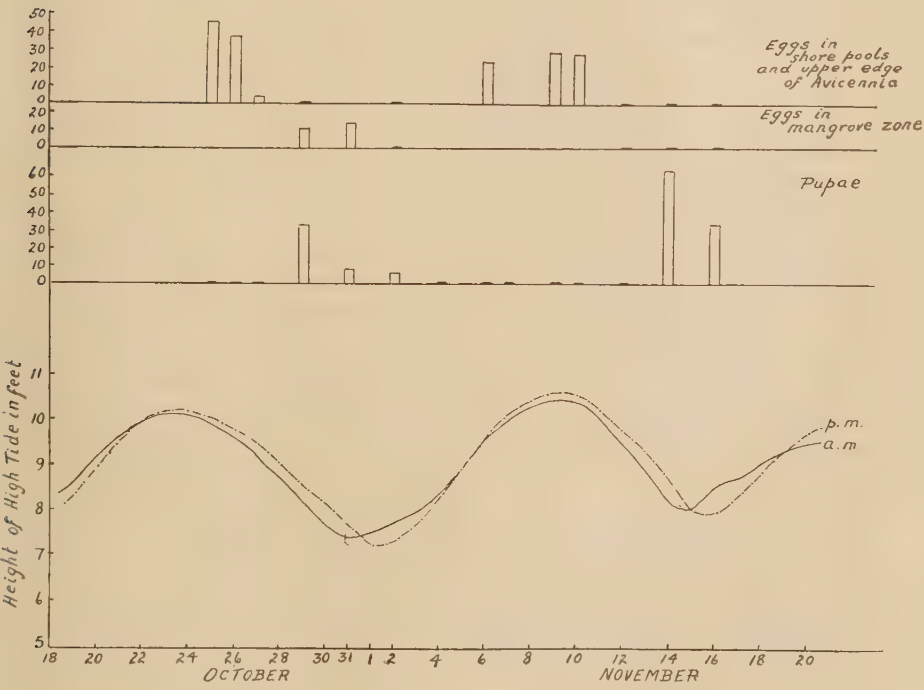


FIG. 4. Aberdeen. *Avicennia* area. Fluctuations in numbers of *melas* eggs and pupae according to the spring tides—October–November, 1942. (Zero observations indicated by thickened base line.)

TABLE II.

Aberdeen. *Avicennia* area. Numbers of *melas* eggs and pupae collected in relation to tidal conditions. October–November, 1942.

Date	Height of high tide in feet	Eggs in shore pools	Eggs in *Avicennia*	Pupae
Oct. 22	10·0			
23	10·2			
24	10·2			
25	10·1	45		0
26	9·9	36		0
27	9·5	4	0	0
28	9·1			
29	8·6	0	12	32
30	8·2			
31	7·8	0	14	8
Nov. 1	7·1			
2	7·3	0	0	6
3	7·7			
4	8·3		DRY	
5	9·0			
6	9·6	19		0
7	10·2	0		0
8	10·5			
9	10·6	23		0
10	10·6	22		0
11	10·3			
12	9·8	0	0	0
13	9·3			
14	8·8	0	0	64
15	7·9			
16	7·9	0	0	34
17	8·3			
18	8·8		DRY	

From these figures it is seen that along the shore and the upper edge of the *Avicennia* there is a peak of egg production at the beginning of each spring-tide period, which leads in five or six days to a peak production of full-grown larvae and pupae. In these pools in which larvae and pupae are particularly abundant, it is very difficult to find any eggs after this initial peak, although a certain amount of egg-laying on a very much reduced scale probably continues, to judge by the presence of occasional very young larvae. At the time of peak production of pupae the pools in the *Avicennia* are no longer reached by the high tides, and a few eggs are found in these pools up to about 50 yards from the shore. Beyond this mark no eggs have ever been found even though larvae extend right to the outer limit of the *Avicennia* zone.

This peak of egg production is mainly responsible for the later peak of pupal production and adult output. But falling as it does at a period when the tides flood the whole area every 12 hours, it is also responsible for the distribution of larvae over a wide area. We have already described how eggs are found in the open water at full tide, where they are carried helplessly on the current. Eggs have been found carried along the shore by the cross movement of the tide, and also being carried well into the *Avicennia* as the tide recedes. There seems little doubt that the wide distribution of larvae over the orchard and along the shore is due to the eggs being distributed helplessly by the ebb and flow of the water at high tide. The fate of these eggs must be varied ; many must be carried out right into the *Rhizophora* and other unsuitable places, and many must be stranded at the highest tide mark in places that dry up quickly and are not flooded till the next series of spring tides.

The fate of those eggs stranded in places that dry up quickly is worth following, as it can be shown that they contribute eventually to the pupal peak in the next series of spring tides, in this way. During the period of neap tides, the whole breeding area may dry up completely a few days before the next spring tides start. Such an area, which had dried up completely, was examined a few hours after the first high spring tide had flooded it. In shore pools and in the *Avicennia*, 49 *melas* eggs and 32 newly-hatched larvae were found. All the *melas* eggs were empty, and no larvae of any other stage were found. The conclusion seems to be that these eggs had been lying dormant in the damp mud and had all been hatched at the same time by the first spring tide. The peak of egg-laying follows at once, and both factors are responsible for the great peak of pupal production about a week later.

Another result of this peak of egg production is that nearly all *melas* larvae, whether developed from dormant eggs or from eggs laid during the highest springs, spend the greater part of their larval period in places flooded by the high tides every 12 hours, some actually reaching the pupal stage while this condition exists. As we shall see later, this is a factor of considerable importance in devising control measures.

Aberdeen (Sea Grass Area). This breeding area, which lies within a few hundred yards of the one described above, is a broad open shore of sea grass and sedge between the *Rhizophora* and the high spring tide mark (fig. 2, *c*). Although there is no *Avicennia* in this breeding area, the ground is equally flat and badly drained. During and after the rainy season it differs from the previous area in having a great deal of fresh seepage water from the hill behind flowing on to it and keeping it in a boggy condition. From June till December this area never dries up completely at neap tides ; it is subject to the same tidal influences as the *Avicennia* orchard described above, but there is a wider range of salinity according to whether the place is flooded by the tide or by seepage water from the land.

During the month of December special attention was paid to the fluctuations in numbers of full-grown larvae and pupae to see if there was any rhythm corresponding to that in the other area. The results are shown in Table III and in fig. 5.

TABLE III.

Aberdeen. Sea Grass Area. Numbers of *melas* eggs, full-grown larvae and pupae collected in relation to tidal conditions, December, 1942.

Date	Height of high tide in feet	Eggs	Full grown larvae	Pupae
Dec. 1	7·3			
2	7·6			
3	8·2			
4	8·9		25	11
5	9·5			
6	10·0			
7	10·4		7	0
8	10·7			
9	10·8		9	1
10	10·6			
11	10·2			
12	9·7			
13	9·2			
14	8·1		32	7
15	7·9			
16	8·1	0	60	30
17	8·3			
18	8·8	0	13	18
19	9·1			
20	9·4			
21	9·6	62	7	0
22	9·7			
23	9·7	61	0	0
24	9·6		DRY	

The spring tides of 19–24/xii were not high enough to flood the breeding ground.

Not till the end of this month did the ground dry up completely, and yet the periodicity of breeding is as well marked as in the *Avicennia* area, with two sharp peaks of pupal production in the month. In the second half of the month the egg collections gave negative findings during the pupal peak, followed by a sharp increase at the spring-tide period. A striking fact here is that the peak of egg-laying started on 21/xii before the high spring tide had reached the breeding ground.

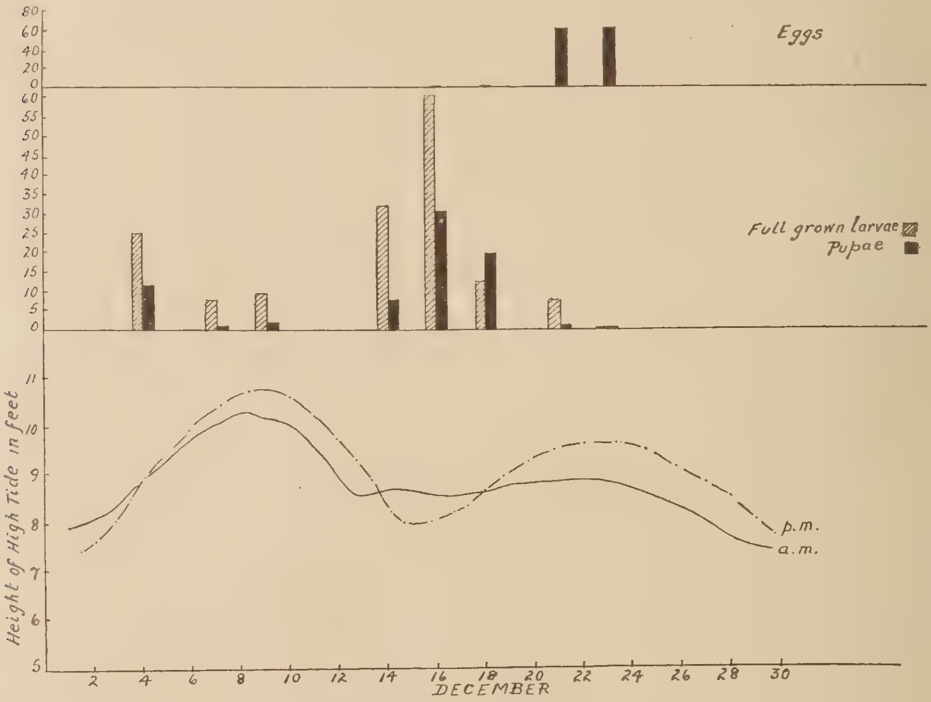


FIG. 5. Aberdeen. Sea Grass Area. Fluctuations in numbers of *melas* eggs, full-grown larvae and pupae in relation to spring tides, December, 1942.

A study of these two areas shows how the peak of egg production gives rise to the peak of pupal production and therefore of adult output. It was concluded from this that conditions during the spring tides must be particularly suitable for oviposition. But in the light of egg counts in the sea grass area at Aberdeen, it seems more reasonable to suggest that the peak of egg-laying is the direct result of a large number of mosquitos emerging at the same time, feeding, and subsequently all laying within a day or two of each other. That the sudden increase in egg-laying happens to coincide with the high spring-tide period would more likely be in the nature of a coincidence than due to any deliberate selection by the female mosquito.

It must be emphasised that the rhythm in egg-laying and in production of pupae described in these two breeding grounds at Aberdeen is only evident in certain months of the year, notably in the period between the end of the heavy rains in October and the end of the main breeding season in January. Even during that period, when the weather is getting progressively drier, conditions vary considerably from year to year, and the spring tides are never quite the same.

When these observations were made in October and November, 1942, the breeding areas were flooded for several days by *both* series of spring tides in the month, and this was undoubtedly very favourable for dense breeding, being reflected by high catches of *melas* adults in nearby houses. But in other years it sometimes happens that only one of the spring tides in the month floods the breeding area for several days (as in fig. 3), the other series of spring tides either not reaching the ground at all, or only flooding it for one or two days, resulting in the ground drying up before the larvae are full grown. If this latter condition occurs after the rainy season, or even at the very beginning of the rains in June, there is a monthly rhythm, large numbers of full-grown larvae being found at the end of the one spring-tide period in the month that floods the breeding area for several days. As the dry weather progresses, even this one long flooding is not enough to prevent the ground from drying up quickly and remaining very dry for over three weeks at a time. In that case even the monthly fluctuation disappears, marking the end of the main breeding season. This question will be taken up later in the light of findings at Wellington and other orchards.

During the period of heavy rain in July, August and September, averaging over 30 ins. of rain each month, the tidal effect is obscured. Much of the breeding ground is flooded continuously, and intermittent heavy showers upset routine collections and observation. Although *melas* breeding may continue fairly high during these months, judging from the number of adults caught, the larvae are evidently scattered over such an area, on a continuous sheet of water, that they are usually very difficult to find. On the few occasions when conditions during that period have made it possible to collect large samples, there has been no obvious relation between number of pupae and state of the spring tides.

In the observations at Aberdeen, attention was concentrated on the effect of tide on breeding conditions, and our information about output of adults was based entirely on the numbers of pupae recovered. Pupal mortality was very low, and it was a reasonable deduction to assume that the peak of pupal production was necessarily followed by a sharp peak of adult output, as happened with pupae removed to the laboratory. No attempt was made to follow this up by studying the fluctuations in numbers of adults caught in nearby catching stations or control houses. This would have been extremely valuable in conjunction with the observations on larvae and pupae, but was not possible at the time. Fortunately, however, this gap has largely been filled by the work of Ribbands (1944*b*) in houses beside those breeding grounds in 1941. Among other things he concluded that in the dry season maximum numbers of *melas* usually occurred about eight days after maximum tides, but that in the wet season there is no indication of any relationship between spring tides and mosquito peaks. He also concluded that, in the absence of rain, tide exerts a marked effect on the size of the population, but that even small quantities of rain greatly reduce the importance of the tidal factor.

The fluctuations of adults in houses is a much more complicated study than determining a simple peak of adult output from the breeding place, as it is affected by so many more factors. The numbers of mosquitos in houses depend on length of life of adults, blood feeding and resting habits, number of blood meals, etc.; nevertheless, the peaks of adult output at Aberdeen are evidently sufficiently marked to make a clear impression on the large population of *melas* adults already in existence.

The influence of rainfall on breeding and on the breeding season will be discussed later.

TABLE IV.

Collections of *melas* larvae from inner and outer parts of Wellington *Avicennia* orchard, at end of spring-tide period, November–December, 1942.

Date	*Avicennia*, near dry land				Outer *Avicennia*			
	28/xi	10/xii	12/xii	Total	28/xi	10/xii	12/xii	Total
First-stage larvae	42	17	13	72	0	0	0	0
Full-grown larvae	6	0	10	16	55	26	19	100
Pupae	1	0	8	9	4	3	1	8

Wellington (Map 2 ; Pl. II, figs. 2–5 ; Pl. IX, figs. 1–2). This is the largest and most important *Avicennia* orchard on the south side of the Freetown estuary. It is about 50 acres in extent and very flat, levels showing a maximum variation of six inches in over 1,400 yards. It belongs to type d (fig. 2, *e*), the *Avicennia* extending right up to high spring tide mark where there is a sudden change to the high bush of the dry land. Larvae have been found over the entire area, from the upper limit of the *Avicennia* outwards to the *Rhizophora*, and extending into the *Rhizophora* for a few yards. The *Avicennia* trees near the upper tide mark are larger than those in the outer parts of the orchard. The part next to the dry land is kept wet by seepages for the greater part of the year, while the outer orchard usually dries up completely during the neap tides.

During the months of the year when periodicity of breeding was so well marked at Aberdeen, production of full-grown larvae and pupae went on more or less continuously at Wellington. In that part of the orchard next to the land, larvae of all stages could always be taken together. But in the outer orchard there appeared to be more regular fluctuations. It was not possible to make the regular visits necessary to give as complete a picture as at Aberdeen, but collections taken near the end of the spring tides show the difference between the inner and outer orchard (Table IV).

This difference between inner and outer orchard is almost certainly due to distribution of egg-laying. No eggs have been found in pools more than about 100 yds. from the dry land (Map 2), and comparatively few in pools more than 50 yds. The vast majority of eggs collected were in quite a narrow zone round the upper edge of the orchard where breeding goes on continuously. At spring tide these eggs must be distributed all over the orchard by the movement of the tides, and many must be stranded in the outer orchard which dries up soon after the end of the spring tides. These eggs will lie dormant in damp mud—as has been proved in the laboratory—for at least a week. When the first high spring tide again floods the *Avicennia* all these eggs hatch at once, producing a crop of larvae that grow together, all reaching full stage about the same time at the end of the spring-tide period. In samples of larvae collected in the outer orchard at that time, young stage larvae are almost completely absent, whereas in the inner orchard all stages of growth are present (Table IV).

In the outer orchard footpaths made by woodmen play an important part in breeding of *melas*. When the rest of the flat ground dries up, these paths and deep footprints are left flooded for a few days longer, many full-grown larvae, which might otherwise have been stranded, may pupate successfully. The incoming tide also tends to advance more rapidly along these paths ; towards the end of the spring-tide period, the incoming tide converging on these paths picks up all the larvae from small puddles and flooded footprints and carries them along till they are stranded in some backwater or among the roots of an *Avicennia* tree. The larvae are evidently unaffected by this flushing to and fro, which happens every 12 hours during most of the period of growth from hatching onwards, and the majority pupate successfully.

Length of Breeding Season.

In the preceding sections it has been shown that although *melas* breeds in sea water or estuary water yet conditions for continuous dense breeding are by no means always present. Not only is breeding affected by different types of spring tide, but over and above that it has emerged that the same type of spring tide may produce different effects according to the season of the year. There is always an abundance of sea water to flood most of the mangroves at high tide no matter how dry the weather, but the main breeding grounds of *melas* happen to be in a part of the mangrove zone only reached by certain tides and particularly influenced by rainfall and fresh water seepages from the land. The combined effect of these factors is reflected most strikingly in the numbers of adult *melas* that can be caught at different times of the year.

By hand-catching alone, it soon becomes evident that in the same village *melas* adults are particularly abundant at certain times of the year, while at other times there is a definite off-season, when for two or three months it may be extremely difficult to find more than one or two adults in a morning's catch. To illustrate the seasonal change most clearly, I am fortunate in having at my disposal the very complete representative figures from all catching stations (control houses) used by the 5th Malaria Field Laboratory (O.C., Lt.-Col. R. F. Tredre). These catching stations are distributed from Aberdeen at the extreme west of the estuary to Waterloo Aerodrome, about 30 miles south-east of Freetown, and well beyond the east end of the estuary (Map 7).

TABLE V.

Total catches recorded by 5th M.F.L. for *melas* and *gambiae*-type in all catching stations from Aberdeen to Waterloo, Sierra Leone, for each month in 1943. (Total *melas* has been estimated from the number of 4-banded *melas* identified.)

Month	*A. melas*	*A. gambiae*-type	Rainfall (inches)
Jan.	80	172	0·01
Feb.	29	241	0·24
March	72	339	0·02
April	44	159	1·87
May	246	387	8·84
June	670	1,895	11·19
July	380	1,826	37·33
Aug.	217	593	40·23
Sept.	286	451	32·51
Oct.	219	243	7·30
Nov.	319	198	5·33
Dec.	290	130	3·50
Total	2,852	6,634	148·37

The figures for numbers of *melas* shown in Table V have been arrived at in the following way. We know that a variable proportion of *melas* adults are 4-banded, the proportion varying in wild-caught samples from 10 to 60 per cent. In the estuary region all 4-banded adults are now recognised as really being *melas*, while the 3-banded may be *melas* or *gambiae*-type. The only really accurate way of distinguishing 3-banded *melas* from ordinary *gambiae* is by identification of eggs laid by each female in captivity. This is rather a laborious method with large catches, and naturally cannot be used when the adults have been collected by spray-killing, or the dead mosquitos sent in from distant field stations. But in the present investigation it was found that in an analysis of the mosquito population in Wellington by egg identification the proportion of 3-banded *melas* to 4-banded *melas* in 731 *melas* was 1·7 to 1, so that by multiplying the number of 4-banded *melas* by 2·7 we get a rough estimate of the total *melas* in the catch. This has been applied to the Malaria Field Laboratory figures, in which the number of 4-banded adults was noted, while all those with damaged or badly rubbed palps were discarded. When the total number of *melas* had been calculated, the remaining adults were classed as *gambiae*-type. Although this method may be highly misleading in small samples, it can be used with large figures to give a reasonable estimate of *melas* incidence. The factor of 2·7 used in Freetown estuary does not necessarily apply in other parts of West Africa, and would have to be calculated afresh.

From Table V it is seen that during the driest months of the year in Freetown estuary (February, March and April) the numbers of *melas* are low. In May there is a marked increase leading in June to a great peak in adult incidence. This June peak of *melas* coincides with an even greater peak of *A. gambiae*-type. In the months of heavy rainfall (July, August and September) the numbers of *melas* are still high, although they fall off considerably compared with June. In the last three months of the year, *melas* numbers remain high compared with those of *gambiae*-type. Finally at the height of the dry season, in February and March, the numbers of *melas* fall off to a very low figure.

The factors that impose a natural control of *melas* in the dry season have already been described (page 198). When the spring-tide period is over, the pools of water dry up more and more quickly as the rainfall becomes scanty and the water table falls. Seepage from the dry land may extend the breeding season till February, and finally at this time of the year only one series of spring tides in the month is usually high enough to flood the *Avicennia* area, and the breeding ground becomes baked hard and dry, with cracked soil, for over three weeks at a time.

In the month of May there are occasional showers of rain which help to maintain the pools left by the high spring tides, but the pools still dry up too quickly for continuous breeding. In June showers are more frequent, and this factor acting together with the spring tides of that month is responsible for wide-spread breeding followed by a very great increase in the numbers of *melas* caught in houses.

The June increase in numbers of *melas* was studied in detail in Wellington village and Wellington *Avicennia* orchard, the largest *melas* breeding ground on the south side of the estuary. The identity of adults caught by hand in the houses was established by egg identification. Examination of intact palps gave the number of 4-banded *melas*; all 3-banded adults were put in small cages 6 × 6 × 6 ins. containing a bowl of water with grass stems on the surface. As eggs were laid over a period of two or three days, four or five adults were put in each cage, and as each laid it was removed and its egg batch identified. About half of the adults put aside in cages laid eggs. From the number of *melas* and *gambiae* egg batches laid, the proportion of *melas* adults in each daily catch was worked out.

TABLE VI.

Proportion of *gambiae* and *melas* adults caught in houses at Wellington from June to Sept., 1943.

Month	Total number of Anophelines	Total *melas*	Percentage of *melas* in catch
			Per cent.
June, first three weeks ..	206	109	53
June, last week	109	104	95
July	261	239	92
August	245	198	81
September	86	81	94

The proportion of *melas* to *gambiae*-type adults in the houses of Wellington from June to September, 1943, is shown in Table VI. The figures for total mosquitos caught give no indication of the total population in each month—that has already been shown clearly in Table V—but are merely included to show the size of sample on which the proportion of *melas* to *gambiae* was based. The figures for June are subdivided to show the effect of the high spring-tide period of that month. In the first half of June, before that spring-tide period, *melas* and *gambiae*-type were almost equally abundant in houses, but in the last week of June there is a sudden increase in *melas* figures, this species now accounting for 95 per cent. of the total catches in houses, while *gambiae*-type has fallen from 50 to 5 per cent. of total Anophelines caught. The predominance of *melas* continues right through the rainy season for the next three months.

In June, 1943, the spring tides took the form shown in fig. 6 & Table VII. The first spring-tide series in the month failed to flood the *Avicennia* orchard, but the second series from 17th to 22nd June flooded the whole orchard for several days, at a time when the pools left behind were maintained by intermittent showers. Towards the end of this spring-tide period –on 21st June—a visit to the orchard revealed very dense breeding. The main breeding ground was in the outer orchard where there were innumerable shallow puddles of warm salty water (up to 50 per cent. sea water). In some pools larvae were so numerous that from a distance of a few yards they could be seen rippling the surface.

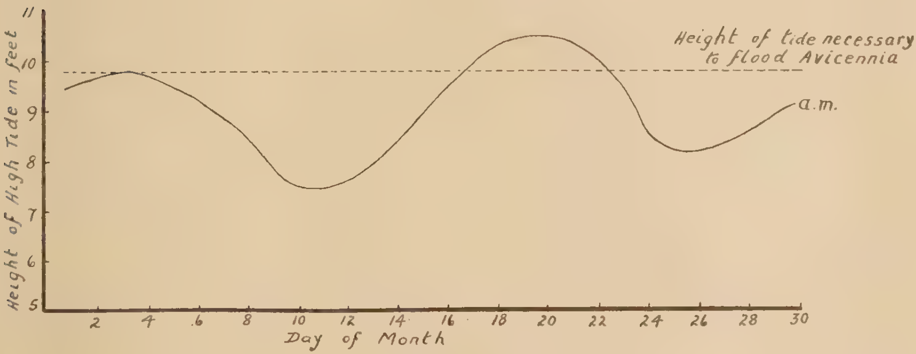


FIG. 6. The critical spring tide of June, 1943, responsible for the June–July peak of *melas* production.

On the following day—22nd June—very similar conditions were seen in the *Avicennia* orchard at Aberdeen, where there were numerous shallow pools swarming with full-grown larvae.

Conditions in both these orchards were evidently ideal for dense breeding, and it is almost certain that every breeding place of *melas* in the estuary was similarly affected. This high spring-tide period undoubtedly marks a critical point in the *melas* breeding season, and the huge numbers of adults produced in this week all round the estuary not only contribute to the malaria peak on shore and in the harbour, but must also help to maintain a high population of *melas* adults during the months of July and August when the heavy rains are making conditions more and more unfavourable for breeding.

Unfortunately, the tide is a variable quantity, and there is not always a well marked high spring-tide period in June which we can point out beforehand as the critical one. The spring-tide series that floods the breeding ground may fall too early in the month to be really ideal for breeding, or it may not flood the *Avicennia* for a sufficient number of days. At this time of the breeding season, as at its close, pools left by the tide may be maintained by showers of rain just that little extra time that determines whether the larvae can pupate and emerge before the ground dries up.

TABLE VII.

High tides in the month of June from 1941 to 1944 at Freetown, Sierra Leone.

Date	Height of high tide			
	1941	1942	1943	1944
June 1	8·7	10·6	9·5	7·6
2	8·0	10·4	9·6	8·1
3	8·0	9·9	9·7	8·6
4	8·2	9·4	9·7	9·0
5	8·5	—	9·5	9·3
6	9·2	8·0	9·3	9·6
7	9·8	7·9	8·9	9·8
8	10·3	8·1	8·6	9·9
9	10·0	8·5	—	9·9
10	10·8	8·8	7·5	9·7
11	10·6	9·1	7·4	9·5
12	10·4	9·4	7·6	—
13	9·9	9·4	7·9	8·3
14	9·5	9·5	8·4	8·2
15	8·9	9·4	8·9	8·4
16	—	9·4	9·5	8·6
17	7·7	9·1	9·9	9·1
18	7·8	8·9	10·3	9·6
19	8·0	8·7	10·5	9·8
20	8·4	8·6	10·5	9·9
21	8·7	8·5	10·3	10·0
22	9·0	7·9	10·0	9·9
23	9·3	8·1	—	9·6
24	9·5	8·5	8·5	9·4
25	9·6	9·0	8·2	9·1
26	9·6	9·6	8·2	8·7
27	9·7	10·1	8·3	—
28	9·6	10·5	8·6	7·6
29	9·5	10·8	8·9	7·5
30	9·4	10·7	9·2	7·6

The number of days on which the *Avicennia* would be flooded by the spring tides is marked by a vertical line.

Reference to the tide tables for the last 4 years (Table VII) shows that in June, 1942, there was a suitable high spring-tide period falling at the end of June and carrying on into July. In 1941 there was also a long high spring-tide period about a week earlier than in 1942. In 1944, however, the tides in June are quite different. The spring tide that floods the breeding areas only does to for about three days and is unlikely to be very favourable. The next high spring tide is in the first half of July, at a time when very heavy rainfall is likely. The present investigation came to an end before June, 1944, and it is not, therefore, possible to assess the effect of this peculiar tide.

Oviposition of melas *in Relation to Salinity.*

The breeding places of *A. melas* are subject to wide ranges of salinity. Pools left by the spring tides may have a salinity higher than that of sea-water itself, while on the other hand heavy showers or the flow of seepage water may keep these pools fresh for days or even weeks. However, as breeding of *melas* is mainly confined to mangrove and salt marsh areas, it seems natural to suspect that salt water plays some part in attracting the female mosquito to such places.

To test this possibility, eggs were collected from pools and small artificial pits in the breeding ground, which had been undisturbed by rain or tide on the night previous to the collection. In this way we could be certain that the salinity of water collected from the pit in the morning was much the same as that in which the eggs were laid. The results of these observations, which were carried out at Aberdeen and Wellington, are shown in Table VIII.

TABLE VIII.

Salinity of waters in which *melas* eggs have been found (100 per cent. sea water is taken as containing 19·00 gms. Cl_2 per litre).

Salinity (per cent. sea water)	Total number *melas* eggs	Number of collections	Average number per collection
90–100	3	1	3
80–90	82	2	41
70–80	22	1	22
60–70	46	3	15
50–60	12	4	3
40–50	43	5	9
30–40	119	7	17
20–30	78	1	78
10–20	339	13	26
5–10	165	5	33
1–5	223	5	45
0·1–1	115	12	9
Below 0·1	17	5	3
	1,164		

(0·1 per cent. sea water = approximately 0·02 gm. Cl per litre.)

From these figures, based on over 50 collections involving more than a thousand eggs, it appears that over a wide range of salinity—from 0·1 to 100 per cent. sea water—egg laying is not influenced by salinity, there being no marked preference either for water of high salinity or of low salinity. On one occasion eggs were collected from three pools within a few yards of each other, with salinities of 66, 4, and 6 per cent. sea water ; eggs found on the same morning were 16, 20, and 20, respectively.

In fresh rain water with no detectable chloride, the only eggs recovered have been those in shallow rain-filled pools at Kline Point in Freetown (page 188), and a few in sweet potato pools maintained by seepages.

From these figures there seem to be only two possible deductions. Either that salinity in itself has no influence on the behaviour of the female *melas* in selecting a breeding place, or that the female is extremely sensitive, being able to distinguish between fresh water and water with a salinity as low as 0·1 per cent. sea water (0·02 gm. Cl per litre) and laying indiscriminately in all salinities provided they are more than 0·1 per cent. sea water. The few experiments carried out in the laboratory tend to support the former interpretation, but this experimental study on the influence of salinity has not really been tackled in any detail, and the solution of the problem must remain obscure for the present.

Detection of *Avicennia* Orchards.

The first *Avicennia* orchards to be investigated, Aberdeen and Wellington, were discovered on foot, and both had been traversed many times before their significance was finally realised. When the association between *melas* breeding and *Avicennia* orchards had been worked out at these two places, it became evident that the problem was a localised one, and that the presence of a single uncontrolled orchard of this nature near the anchorage or sea-plane base might nullify anti-malaria measures against *A. gambiae*-type in that neighbourhood. It was imperative therefore to extend the observations further afield and locate the main breeding grounds.

Exploring on foot in the mangroves is a slow and tedious business, and if we had to rely on that method alone little progress would have been made.

Fortunately the mangroves on the south side of the estuary could be viewed from high ground, particularly from Upper Allen Town, and the relation of rivers and creeks seen more clearly. In the rainy season the mangroves appear as a uniform belt of green foliage, becoming dark green where the high mangroves line the creeks and the estuaries. At that time of the year there is no certain way of picking out the *Avicennia* orchards from the low *Rhizophora*. But in the dry weather a change appears, and the foliage of the *Avicennia* stands out clearly as a paler green than the other mangrove. At this time of the year there are three shades of green foliage distinguishable ; very dark green is the high mangrove, the tallest *Rhizophora* trees lining the creeks and forming the outer belt of the mangrove zone ; medium green is all the other *Rhizophora*, which forms the bulk of the mangroves ; the light powdery green is the *Avicennia*, further distinguished by the rounded crowns of the trees (Pl. IX, figs. 1–2).

This method of detection had its limitations as the area of mangrove which could be clearly seen from the high ground was only a small part of the whole estuary. Aerial reconnaisance was then tried. Thanks to the co-operation of the Fleet Air Arm at Hastings, two flights were made in a Swordfish with an open cockpit over the mangrove belt south and east of the estuary. New orchards were detected, but the results in general were disappointing. It is difficult to get a clear uninterrupted view from the plane and to recognise landmarks and fix one's bearings over the confused tangle of mangrove and creek.

Finally, vertical aerial photography was tried and has proved so valuable that it was used wherever possible. The R.A.F. had taken series of vertical aerial photographs of Freetown area, and had built up a large mosaic of the surrounding districts. In the mosaic itself, the definition was seldom clear enough to enable the *Avicennia* to be mapped with confidence, but when enlarged prints were made from the original negatives the results were very striking, and one could pick out clearly *Avicennia* areas in parts of the estuary that had never been visited. The aerial photographs were taken from 5,000 feet, and when enlarged 2–2¼ times gave the appearance of the swamp as if it were viewed from 2,500 feet. This was quite large enough to give perfect definition.

As each mosaic was made up of hundreds of separate prints, only those in the mangrove belt were selected for enlargement, and the number of enlargements was therefore kept low and manageable. For example, the mangrove belt south of the estuary, between Wellington and Hastings, was covered completely by about 20 prints.

These clear prints could be studied at leisure, and the exact location, size and relationship of each *Avicennia* orchard worked out. From the photographs it was possible to find out the best way of reaching unknown orchards, thus saving a great deal of time, and this was particularly valuable in the case of the island orchards. As was described on page 189, these island orchards are isolated stands of *Avicennia*, completely surrounded by *Rhizophora*, and separated from the mainland. They could never have been discovered on foot, and even if their presence had been known, they could hardly have been reached through the tangle of *Rhizophora* without careful study of photographs to give the best method of approach. How valuable these photographs were in the survey of the Bullom Shore will be described more fully later.

In these prints attention was concentrated on the mangrove and breeding places of *melas*, but it is obvious that an immense amount of other information could be gained if necessary, a fact that has been fully appreciated for many years by the tsetse fly research workers in making their vegetation surveys.

The extent of *Paspalum* and *Raphia* swamps can be determined ; the exact course of rivers, creeks, and drains is clearly defined ; the size and relationship of villages can be seen, as well as the exact location of outlying houses or groups of houses in relation to breeding places and, finally, as a method of supplying accurate and up-to-date maps of special areas, aerial photography must take an increasingly prominant part in anti-malarial work.

Avicennia Orchards and other Breeding Grounds of *melas* in Freetown Estuary.

South Side of Estuary (Maps 3, 4, 5 ; Pls. IX, figs. 1–2 ; X, figs. 1–2 ; XI, fig. 1). Between Aberdeen on the west and Hastings on the east there are several *Avicennia* orchards. Although many of these appear to be suitable, frequent visits have shown that Aberdeen and Wellington are the only breeding areas of first importance along the south side of the estuary. For purposes of reference, a list of these orchards from west to east is given (Maps 4, 5).

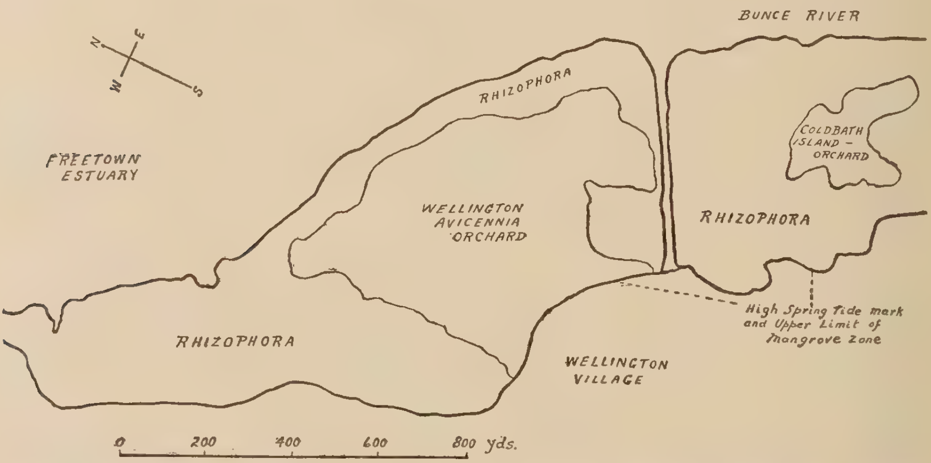
Aberdeen. The sea-grass area and adjacent *Avicennia* orchard have already been described. The *melas* produced from these two breeding grounds were responsible for the high catches of *melas* in houses at Aberdeen recorded by the 5th Malaria Field Laboratory in 1941 and 1942. High catches of *melas* have also been made by myself in isolated beach defence huts on the shore between Aberdeen and Lumley in 1942, and also in houses on the east (Cockerell) side of Aberdeen Creek. Freetown to the east of the creek is partly protected by the Wilberforce and Signal Hill Spur, and only occasional *melas* have been found in house catches in west Freetown (Brookfields). The Aberdeen peninsula, important in war time for its naval personnel, remains the area most affected by these breeding grounds, and it was here that Ribbands recorded his highest house catches in 1941. This breeding area is also important in that it is probably the one affecting ships in the western end of the anchorage. On the Cockerell side of the creek *melas* is occasionally abundant in the few houses situated on the shore opposite the breeding grounds, but the figures of the Malaria Field Laboratory show that Cockerell barracks is not much affected by *melas*, and Wilberforce even less.

At the south end of Aberdeen Creek there is a small boggy patch of sea grass (Pl. II, fig. 1) about 65 × 20 yards, in which *melas* occasionally appear in large numbers. This breeding area, right outside the mangroves and a miniature of the sea-grass area at Aberdeen, was found breeding *melas* in December, 1942, and again in November and December, 1943. In one catch in an isolated house near this breeding ground over 40 *melas* adults were caught by hand on 10.xii.43. The house and breeding ground are only a few hundred yards from the European Clubhouse on the shore, where civilians and service personnel are accustomed to sit about in shorts till after dark. The breeding ground is small enough to be eliminated by draining and filling in between the drains, or even by filling alone.

A small patch of *Avicennia* at the mouth of the Babadori River looks suitable for occasional breeding, but has not yet been incriminated.

Not a single breeding place of *melas* has been found along the entire east (Cockerell) side of Aberdeen Creek.

Wellington. This is the biggest and most important orchard east of Freetown (Map 2, Pls. II, figs. 2–5 ; IX, figs. 1–2). Its effect is most obvious in Wellington village, whose high population of *melas* has already been described. To the west it barely affects the outskirts of Kissy village, but is considered very important from the point of view of shipping off Kissy and at the eastern end of the anchorage. *Melas* adults—3 *melas* and 7 *gambiae* in one catch—have been found aboard ships lying off Kissy oil tanks, and in view of plans for developing the naval base at this part of the estuary, the control of Wellington orchard is essential. The bunding and reclamation of this orchard were well advanced by the time this investigation terminated in April 1944.


BUNCE RIVER
N
E
W
S
RHIZOPHORA
FREETOWN ESTUARY
WELLINGTON AVICENNIA ORCHARD
COLDBATH ISLAND – ORCHARD
RHIZOPHORA
RHIZOPHORA
High Spring Tide mark and Upper Limit of Mangrove Zone
WELLINGTON VILLAGE
0
200
400
600
800 yds.

MAP 2. The Mangrove belt at Wellington showing Wellington *Avicennia* orchard and Coldbath island-orchard. (Drawn from aerial mosaic.)

Coldbath Island-Orchard. This island-orchard lies a few hundred yards to the east of Wellington orchard (Pl. IX, fig. 2 ; Map 2). Within its area of 7–8 acres, conditions appear ideal for *melas*, with a fine thick layer of peaty soil and decaying leaves. Larvae of all stages were found in August, September, October, November and December 1943, the largest number being in August when larvae were found throughout the orchard, 93 being collected. In 16 visits 274 larvae were found. Its importance is probably dependent on its proximity—less than ¼ mile—to the Wellington orchard.

Like other island-orchards (fig. 2, *f*), this one dries up quickly after spring tides, and by January larvae have almost completely disappeared. It is fairly certain that the elimination of Wellington orchard will have a marked effect on this one, and at present control is not being advocated.

Old Wharf Orchard. (Pl. X, fig. 1.) A small patch of *Avicennia* on soil which is mostly too sandy or gravelly to be suitable for *melas*. Only six larvae have been found in three visits, and it is considered quite unimportant.

Kola Tree Island-Orchard. A peculiar T-shaped island-orchard well separated from the mainland (Pl. X, fig. 1). Conditions appear suitable but only small numbers of larvae have been found in a search of the whole orchard in August and November. In seven visits 49 larvae were found, the great majority being early stages. No larvae were found after the beginning of November, and the orchard is considered unimportant.

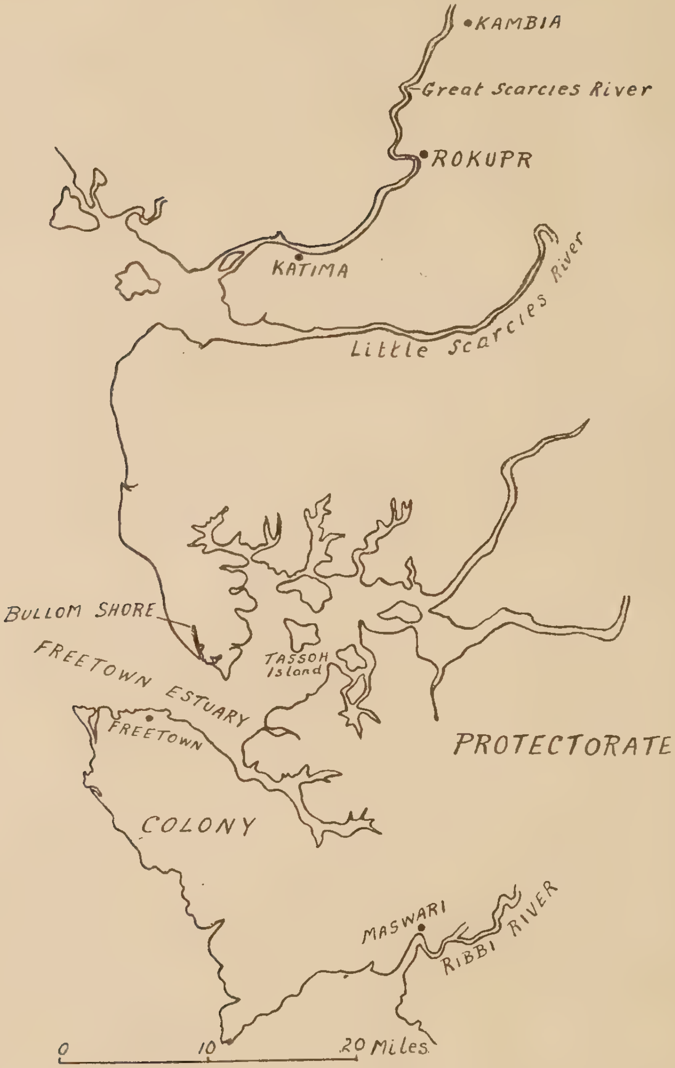
Allen Town Island-Orchard. A compact orchard on the banks of a wide creek (Pl. X, fig. 2), well separated from the mainland. In six visits 47 larvae were found, all of them early stages and most of them in July. No larvae were found here after August, and the orchard is considered quite unimportant.

Hastings Point, Robungba Orchard. When this orchard was discovered on foot as the only suitable looking place for *melas* in the whole Hastings peninsula, it was thought to be an important discovery as the possible origin of *melas* affecting the Fleet Air Arm at Hastings and the seaplane base at Jui. Frequent visits, however, have shown that it is of very minor importance. In nine visits 74 larvae were taken in the whole orchard, 46 of these in one visit in June. Visits paid at very suitable times in October and November, when big numbers of larvae were being found at Wellington, yielded a complete blank.

This is almost certainly an orchard which has been rendered innocuous by village removal. In 1941 there was a native village, Robungba, near this orchard at the tip of the Hastings peninsula. Mosquito collections made in that year by the 5th Malaria Field Laboratory showed high catches of *melas* in the village. By 1942 the village had been removed, and the native population had all been cleared out of the peninsula. It seems fairly certain that when the village existed, the adjacent orchard was a main breeding ground of *melas*. Now, with the nearest village two miles away, it is of minor importance.

Kambia Island South. (Pl. XI, fig. 1.) This was another *Avicennia* orchard, the discovery of which was going to explain the origin of the *melas* mosquitos at the seaplane base of Jui, because of its proximity and in view of the complete absence of any other suitable looking places round the whole Jui peninsula. The orchard looks quite suitable, though the soil is rather sandy and liable to dry up quickly. This orchard has always been negative, not a single larva being found in nine visits.

Kambia Island North. Here a narrow strip of *Avicennia*, with a deep pool acting as reservoir, is a very localised breeding place of *melas*. In one visit in December, 87 larvae and 5 pupae were found, and two other visits in the same month were positive. This small patch has the distinction of being the nearest breeding place of *melas* to Jui yet discovered. There is now no native village on Kambia Island, and the nearest African village on the mainland, Moyene, is being moved. For this small patch, only a few yards square, felling the *Avicennia* and filling in with sand had been recommended.


KAMBIA
Great Scarcies River
ROKUPR
KATIMA
Little Scarcies River
BULLOM SHORE
FREETOWN ESTUARY
TASSOH Island
FREETOWN
PROTECTORATE
COLONY
MASWARI
RIBBI RIVER
0
10
20 Miles

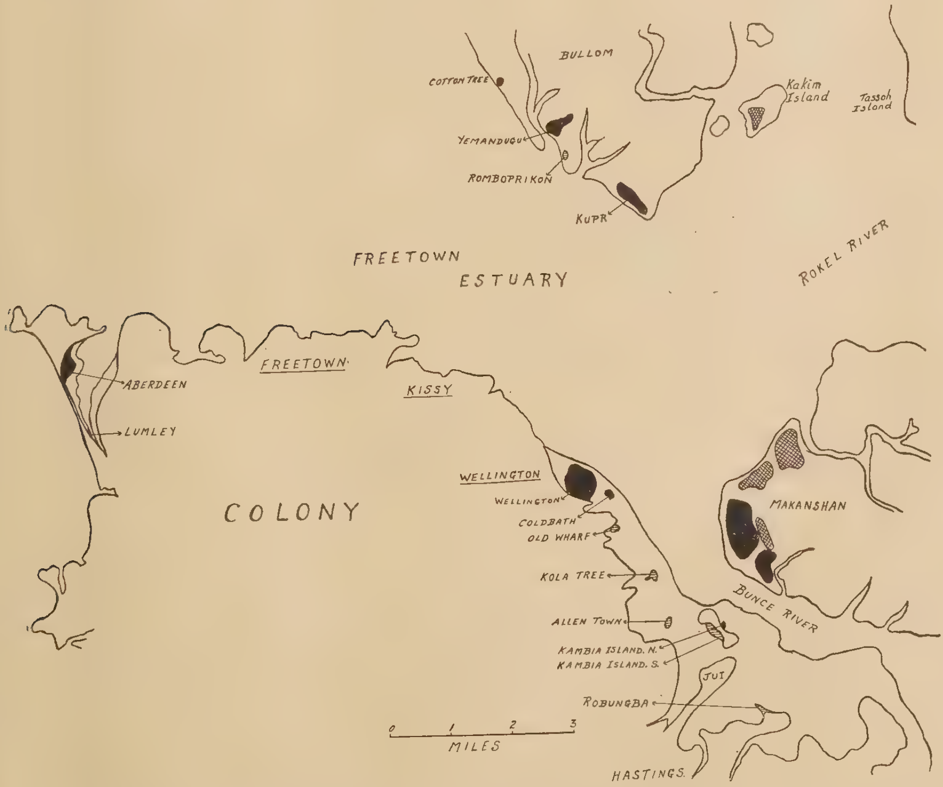
Map 3. The coastal region of Sierra Leone showing Freetown Estuary area and other localities investigated.

In the great stretch of mangroves from Hastings to Waterloo no *Avicennia* orchard has yet been found. Much of this coastline has been covered on foot, but in the absence of aerial photographs, odd breeding patches may have been overlooked. It seems likely, however, that this region is not a good one for *melas* ; adult catches at suitable times of the year, in isolated villages at the mangrove edge, have yielded only odd *melas* adults, which could easily be accounted for by infiltration from the other side of the Bunce River.

In the mass of mangroves between Hastings and Jui, aerial photographs reveal two or three small island orchards, which appear to be inaccessible. In view of the findings in Kola Tree and in Allen Town island-orchards, it is unlikely that these small islands of *Avicennia* are of any importance.

East End of Estuary. (Map 4.)

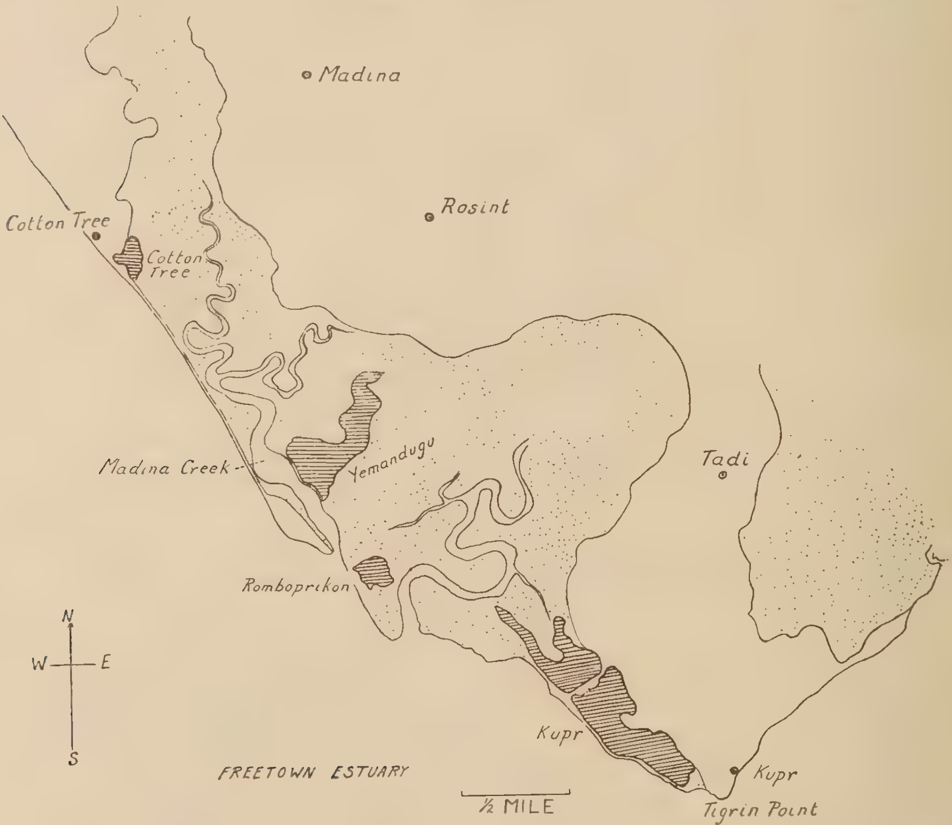
Makanshan. The Makanshan shore forms the east boundary of the Freetown estuary, and lies between the Bunce and Rokel Rivers. Attention was first drawn to this place early in 1943 when an aerial reconnaissance showed extensive tracts of *Avicennia.* Difficulties of launch transport made frequent visits impossible, but in each visit large catches of *Anopheles* were made in Makanshan village itself. Of 197 adults caught in houses between October and December, 1943, 91 per cent. were identified as *melas* by egg examination, the remainder being *A. gambiae*-type. The latest catch was almost entirely *melas.* The people in these houses said that mosquitos at that time of the year were not troublesome, but that in June and July they made the nights unbearable. Extensive breeding grounds were finally discovered near Alligator Creek, in that part of the *Avicennias* across the Bunce River from Jui. This area is considered one of first importance in so far as it affects the seaplane base at Jui, and the " trot ", that part of the Bunce River where the seaplanes land and lie out at night. From the high numbers of adults caught in October-December, there must be a huge output in June, the peak period in the estuary. In June and July the coastal villages between Wellington and Hastings have all high populations of *melas,* particularly Pamiwonko, Allen Town and Moyene. *Melas* is also found in Upper Allen Town and the Malaria Field Laboratory has recorded it from Grafton Valley. It seems pretty certain that Makanshan is responsible for much of this, and that it will have to be dealt with.


BULLOM
COTTON TREE
YEMANDUGU
ROMBOPRIKON
KUPR
Kakim Island
Tassoh Island
FREETOWN
ESTUARY
ROKEL RIVER
ABERDEEN
LUMLEY
FREETOWN
KISSY
COLONY
WELLINGTON
WELLINGTON
COLDBATH
OLD WHARF
KOLA TREE
ALLEN TOWN
KAMBIA ISLAND. N.
KAMBIA ISLAND. S.
JUI
ROBUNGBA
HASTINGS.
MAKANSHAN
BUNCE RIVER
0
1
2
3
MILES

MAP 4. The main breeding places of *A. melas* in Freetown Estuary. Breeding places (mainly *Avicennia*) of first importance, shown dead black. Breeding places (*Avicennia*) of minor importance, shown striped. *Avicennia* orchards not fully investigated, shown cross hatched

Apart from Makanshan village, which is only a small one, there are very few habitations in this area, and village removal is recommended. If this were done the nearest regular source of blood meal would be two miles away on the mainland of the Colony, and it would be unlikely for dense breeding to continue. At the same time it would be advisable to visit the known breeding grounds from time to time in order to confirm this.

North Side of Estuary. The Bullom Shore (Map 6 ; Pls. XI, fig. 2 ; XII ; XIII, figs. 1–2). The importance of the Bullom Shore as a breeding ground for Anophelines was first made evident by the pioneer work of Blacklock & Wilson (1941), and it was also shown that a good proportion of mosquitos caught in houses were *melas*—as judged by adults with 4-banded palps. In the present investigation, the launch situation in the estuary was so critical that it was impossible to follow up the findings made on the south side of the estuary by paying regular visits to Bullom Shore.



Map 6. Bullom Shore. Mangrove belt from Cotton Tree to Kupr showing *Avicennia* orchards (striped). (Drawn from aerial photographs.)

In October, 1943, a special effort was made, and with the help of the Harbour Master and Mr. Neil Shooter, Malaria Propaganda Officer, about a dozen visits were made between then and January. In the normal course of events little could have been achieved in these infrequent visits, but fortunately the R.A.F. provided copies of a mosaic of the Bullom Shore, and enlarged prints of the mangrove belt from Cotton Tree to Tigrin Point (Map 6 ; Pls. XI, figs. 1–2 ; XII ; XIII, figs. 1–2). These photographs were so perfect that it was possible to get the fullest possible value from each trip, and to locate the main breeding places of *melas* in the shortest time.

In order to ascertain whether the major problem here was one of *melas* or of *gambiae* type, collections of adults were made in the villages of Cotton Tree, Kupr, Madina, and Tadi, at intervals between October and February. When the Blacklock Report was written, only those adult mosquitos with 4-banded palps were recorded as *melas*, all 3-banded being listed as *A. gambiae*. In the light of findings by Ribbands and by myself in the last two years, we now know that many of the Bullom " *A. gambiae* " must really have been 3-banded *melas*, only distinguishable from typical *gambiae* by the eggs they lay. In this investigation therefore the mosquito population of the Bullom villages was analysed by egg examination so as to give a more exact idea of the relative importance of these two species. The results are shown in Table IX.

TABLE IX.

Catches of adult *melas* and *gambiae* in Bullom villages, October, 1943, to February, 1944.

Village	Number of visits	Total Anophelines	Total *melas*	Proportion of *melas* in catch
				Per cent.
Cotton Tree	9	365	330	91
Kupr	1	66	63	95
Madina	4	128	37	29
Tadi	2	162	133	82

From this table it will be seen that during this period of the year at least, October to February, over 90 per cent. of mosquitos caught in the coastal villages, Cotton Tree and Kupr, are *melas*. Tadi, further inland, but still surrounded by mangrove areas, has over 80 per cent. *melas*. While Madina, 1¼ miles inland from the mangroves belt, has less then 30 per cent. *melas*, *gambiae*-type evidently being the dominant mosquito there.

The villages in which these hand catches of live mosquitos were made were supposed to be, and in some cases actually were, sprayed with Pyefly daily as an anti-adult measure. Otherwise the catches might have been much higher. As it is the large numbers recorded do not speak well for the efficacy of spray killing alone in the complete absence of anti-larval measures.

Of the five main *Avicennia* orchards between Cotton Tree and Tigrin Point, three have been shown to be major breeding grounds of *melas* of first importance, the density of breeding being comparable to that of Wellington orchard at its peak period. Reference to the aerial photograph (Pls. XI, fig. 2 ; XII ; XIII, fig. 1) will show that on the Bullom Shore most of the mangrove belt is protected from the sea by a long sand dune, a narrow spit of dry land, and that the whole mangrove belt is flooded by the tide flowing in through comparatively narrow creeks then spreading out in all directions behind the sand dune. This formation is quite different from that of the south and east banks of the estuary, where the whole mangrove zone is fully exposed to the estuary along its entire outer edge. The mouths of the Bullom Creeks are sandy and unstable, and since these photographs were taken (Pl. XII), the Madina creek has broken through the narrow sand bank, opening to the sea by a new mouth about 800 yards to the west of the old one. This sort of incident bears out the engineers' opinion that any attempt to make use of these narrow entrances, by constructing a bund which would prevent the tide from flooding the whole mangrove zone, would be a major engineering project.

The three main *melas* breeding grounds are as follows :—

Cotton Tree (Map 6 ; Pl. XI, fig. 2). This small orchard was discovered on foot, and it is particularly important because of its proximity to Cotton Tree village on the shore. Breeding has been found all over this orchard as well as in some pools among *Paspalum* at the edge of the orchard, pools which dry up slowly and act as reservoirs when the rest of the orchard is dry. It is protected from the sea by a broad sand bank with thick bush, and from the creek by a broad belt of *Rhizophora*. The whole orchard is being bunded off and reclaimed.

Yemandugu (Pl. XII). This a fairly extensive orchard with the densest breeding at its south portion next to Madina Creek. This part of the orchard has some of the largest *Avicennia* trees yet encountered, an exceptionally thick carpet of long pneumatophores, and several large pools which still contain water and numerous larvae when the rest of the orchard has dried up. The whole orchard is well protected from the sea and from wave action, and it is planned to reclaim the whole area by bunds.

Kupr South (Pl. XIII, fig. 1). This is a very extensive orchard of large *Avicennia* trees, opening out on the landward side on to a flat *Paspalum* and sedge swamp. The seaward side of the orchard is protected from the sea by a long dune, at both ends of which the tide enters through comparatively narrow creeks and spreads out to flood a wide area behind the dune. From the density of *melas* larvae here, and their wide distribution through most of the orchard, this is considered the greatest breeding ground on the Bullom Shore, and the one whose control is most urgently required. The high catches of *melas* adults in Kupr village to the east, and at Tadi to the north, are almost certainly due to this orchard. Its position near the extreme south of Bullom Shore also brings it within one mile of ships in the northern anchorage of the estuary. Plans have been made for reclaiming this orchard by building bunds at either end, and keeping the spring tides from flooding round the back of the orchard.

Kupr North (Pl. XIII, fig. 1). This *Avicennia* orchard, of smaller more widely-spaced trees, looks suitable, but not a single larva was found at a time when there was dense breeding in Kupr South. It will probably be included in the scheme for reclaiming the latter orchard.

Romboprikon (Pl. XII). A small island-orchard with considerable intrusion of *Rhizophora*. The ground seems to be on a lower level than that of the usual *Avicennia* orchard, being more frequently flooded by the high tides. No larvae have been found in this orchard, and its reclamation is not being considered.

A study of the aerial photographs shows that there is a fairly extensive orchard north of Tadi. This has not been visited, and is not sufficiently near the south coast of Bullom to demand immediate attention.

Kakim Island (Pl. XIII, fig. 2). This island lies roughly midway between Tigrin Point and Tassoh Island. Aerial photographs showed a well developed *Avicennia* orchard. It was first visited at the end of January, 1944, at a suitable stage of the spring-tide period. The orchard looked very suitable but no larvae were found, which at that time of the year is not conclusive evidence one way or the other. There are two small groups of houses at each end of the orchard, one of which, Yelkakrom, lies on the Bullom-boat route from Port Loko to Freetown, and is used as a nightly stopping place for boatmen waiting for a suitable tide. The iron ore ships to and from Pepel pass this way also.

Of 16 adults from one house in Yelkakrom on 1.ii.44, all were *melas*. The orchard may be important for a part of the year and could be definitely incriminated or otherwise by visits at the end of the spring-tide periods in June and July or in October and November.

Tassoh Island (Maps 3, 4). This island was investigated by Blacklock and Wilson, and found to be an important breeding ground of freshwater *gambiae*, larvae being found in numbers round the swampy edge of a fresh water lake. Banking up by the spring tides had interfered with the drainage of this swamp, and a short bund and tidal gate had been installed to overcome this difficulty.

In the present investigation Tassoh Island was visited in July, 1942, before the control measures had become well established. The egg differences had not yet been discovered, but out of 82 adults caught in houses, only three were 4-banded (*melas*), and the majority of eggs laid by the remaining mosquitos were later known to be those of *gambiae*-type. On 5.xi.43 only small numbers of adults could be found in houses on Tassoh at a time when there were large catches recorded from the Bullom Shore villages. Of 18 adults, 12 were *gambiae* and 6 were *melas*. There are small patches of *Avicennia* on the island, but the adult catches suggest that *melas* is not a major problem here.

On Pepel Island nearby *Anopheles* were very scarce at the same time, November, only 3 *gambiae* type being found in the whole village by two collectors. Although these figures are scanty, they were taken at a time of the year favourable for *melas*, and they seem to indicate that in this north-east corner of the estuary there are no great breeding grounds of *melas* corresponding to those of the Bullom Shore.

The Control of *melas* Breeding Places.

When this investigation started in July, 1942, anti-larval control of *melas* in the whole Freetown estuary was practically non-existent. In the absence of any definite knowledge about the breeding places of *melas*, this was inevitable. By that time the work of Blacklock and Wilson on the Bullom Shore and that of Ribbands at Aberdeen had shown that in those localities at least *melas* was a particularly abundant house-haunting mosquito, and that it must play some part as Blacklock's dissections showed—in the malaria picture. The only large breeding ground known at that time was the sea-grass area at Aberdeen. A drainage scheme for this area had been constructed by the 49th Field Hygiene Section in 1941, but no attempt was made to keep the spring tides from flooding this drained area.

The present investigation showed on the one hand that *melas* was a much more important mosquito in the estuary than had been realised, and on the other hand that although the *Avicennia* orchards were found to produce enormous numbers of *melas*, the number and character of these orchards were such as to suggest the possibility of ultimate control.

Effect of Drainage alone. In the previous sections it has been shown that the high spring tides not only provide the breeding places of *melas*, but that they also, by their ebb and flow, distribute eggs and larvae throughout the orchard. It was also shown that the first high spring tide to cover the breeding area after it had been dry for a few days, hatches eggs lying dormant in the mud, and creates pools in which eggs are laid on the following nights. The larvae from these eggs are nearly full-grown by the end of the spring-tide period, most of their development taking place while the ground is being flooded twice a day by the high spring tides.

From these facts it is evident that drainage alone to be effective would have to dry up the surface pools completely a few hours after the last high spring tide had left the area. This might be possible in a very small breeding patch, but with a large flat expanse of *Avicennia* would not be effective, especially in the rainy season.

The sea-grass area at Aberdeen, which is about 500 by 100 yards, was drained in 1941 with a view to control. The drainage evidently made the ground much less boggy, and probably had a distinct controlling effect in the driest months of the year, January to March. But in the latter part of 1942 large numbers of larvae were found in boggy patches between the main drains from October to December. The effect of the drains was offset by seepages from the land, which resulted in this sea-grass area drying up more slowly during the neap tides than the adjacent undrained *Avicennia*.

The sea-grass area is a much less extensive breeding ground than the main *Avicennia* orchards, and it is almost certain that drainage alone in those orchards would be even more ineffective. In fact, there is evidence to show that drains dug in a flat *Avicennia* orchard, which is still unprotected from the spring tides, may create breeding places where none existed before. For example, during bund construction in the Aberdeen *Avicennia* area in the dry weather of January to April, 1944, shallow drains had been dug, and a series of shallow borrow pits outside the bund had not yet been connected. Normally at this time of the year the whole area dries up very quickly at the end of the spring tides, and may remain quite dry for two or three weeks. But in these pits, and in the shallow drain still being flooded by sea water, salty pools were left behind for many days and contained large numbers of *melas* larvae and pupae.

*Bunding.** In view of all these facts just described, it soon became evident that no real control could be achieved unless the spring tides were kept off the flat *Avicennia* area. At this time the Agriculture and the Irrigation and Drainage Departments were planning extensive swamp reclamation schemes for rice cultivation ; one of these smaller schemes, which had been in operation for two or three years, was particularly instructive for our purposes. Mr. H. Macluskie of the Agricultural Department was kind enough to demonstrate this area to myself and Lt.-Col. Tredre. About ten acres of *Avicennia* and *Paspalum* swamp at Maswari on the Ribbi River had been surrounded by a low bund to keep the spring tides out. Internal to the bund the plots were kept flooded with fresh water ; and in the bund itself had been incorporated a simple hand-operated sluice gate, not for the purposes of draining the plots, but rather to control the depth of water in the rice fields.

With this example, constructed on much the same type of ground on which *melas* breeds, the first bunding experiment was started at Aberdeen, with the co-operation of the 5th Malaria Field Laboratory and of the 49th Field Hygiene Section (O.C., Major Birmingham), which carried out the construction work. Mr. Rae, Director of the Irrigation and Drainage Department, gave us advice on bund and sluice gate construction.

At Aberdeen one length of bund ran along the upper fringe of the *Rhizophora*, protecting the whole sea-grass area (Map 1), while another loop of bund ran through the *Avicennia* orchard protecting the upper half of the orchard where most of the breeding and egg-laying took place. At that time we had no idea what would happen in the reclaimed area, and as there seemed a possibility that fresh water pools on the flat ground might introduce a *gambiae*-type problem, the experiment was designed to find out if partial bunding could eliminate most of the *melas*, while keeping the reclaimed area small enough to be dealt with if necessary. The effect of this partial bunding on the Aberdeen *Avicennia* area has not yet been fully tested ; work on this section was not completed till early in 1944, when the dry weather had reduced *melas* breeding to a minimum. Before bunding was started, breeding in the outer half of the *Avicennia* orchard was shown to be caused mainly by eggs and larvae being dispersed from the upper half of the orchard. Now that the bund is finished this outer half is separated from the inner part and is still flooded by spring tides. It remains to be seen whether the amount of breeding outside the bund remains low enough to be unimportant, or whether complete control can only be achieved by running another bund round the periphery of the orchard. The engineers have assured us that a properly designed system of internal drainage should be efficient enough to eliminate surface pools from the reclaimed area, except during those odd periods in the rainy season when the rain falls continuously for two or three days without ceasing. While these bunds are being constructed and while the internal drainage is still incomplete, it is possible that breeding may continue and even be aggravated (see page 216) in some cases. In other cases, as will be described in the next paragraph, almost complete control has been achieved even when the internal drainage has been incomplete and inefficient from an engineering point of view.

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* " Diking " of the Americans.

In the sea-grass area, the whole breeding ground is protected by a bund completed about August, in the rainy season of 1943. The bund stood up successfully to some of the highest spring tides of the year, but to begin with internal drainage and the automatic tidal gate were not efficient enough to drain away, at low tide, all the fresh water that had accumulated in the reclaimed area during the period of several hours when the sluice gate was shut against the high tide water (fig. 7). As a result much of the breeding ground remained boggy with fresh water at this time, but strangely enough breeding was almost entirely eliminated, protection from the spring tides alone producing quite effective control. The odd larvae found were all *melas*, and no *gambiae*-type invaded these fresh water pools. Despite these drainage defects, the bunding had completely eliminated *melas* during the months of October to December, a period when there had been dense breeding here in the previous year, 1942.

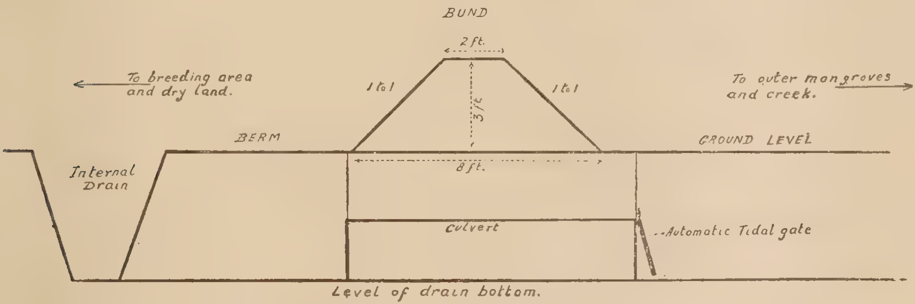

FIG. 7. Cross section of bund where it incorporates a sluice gate showing general design.

The demonstration at Aberdeen is considered quite sufficient to show the great possibilities of bunding in control of *melas*. The policy now with regard to other orchards is to imitate the reclamation of the sea-grass area at Aberdeen, by surrounding the whole orchard with a peripheral bund, rather than attempt the still untested partial bunding. From what has been said above, it is evident that the problem is mainly one for the engineers, and that the control scheme can be seriously upset by defective bunds, drainage, or sluice gates. As to the bund itself, it now takes the form shown in fig. 7 and Pls. III, figs. 1, 3, 4 ; IV, fig. 1. All *Avicennia* orchards bear much the same relation to the height of the spring tides, and a bund 3 -3½ feet high is considered sufficient. In some places it is found expedient to cut across patches of *Rhizophora* rather than follow the exact edge of the *Avicennia*, and such portions, being on a lower level, need the bund to be correspondingly higher. The material for the bund comes mainly from an internal drain excavated at the same time. But as the bund consolidates, more mud is needed, and this should be taken from the surface of the reclaimed area, not, as native labour tends to do, from the berm itself or from the soil immediately outside the bund. Both the latter practices tend to weaken the bund. The digging of random borrow pits for soil should also be discouraged, although constant supervision is necessary to ensure this order being carried out.

In most *Avicennia* orchards the peaty soil is ideal for bund construction, but in some places, *e.g.*, at Aberdeen, there are patches of sandy soil quite unsuited for bunds. In some places the peaty layer is quite thin, and too much sand is incorporated in the bund, which then tends to crumble. In such cases salt water creeping plants, which appear on the settled bund very soon, should be encouraged to bind the soil.

In most orchards there is a good belt of *Rhizophora* between the outer edge of the *Avicennia* and the sea or estuary. The deeper this belt the greater the protection of the bund from wave action. At Wellington the belt of high *Rhizophora* had been felled for mangrove fuel a short time before it was decided to tackle the big *Avicennia* orchard (Pl. IX, figs. 1–2). A bund was built along the upper edge of this clearing, but had to be abandoned because there was no protection from waves of the estuary. The bund was later moved further back to leave some *Avicennia* and uncut *Rhizophora* between it and the sea. With anti-*melas* schemes now more clearly defined, the policy of the Forestry Department, who are interested in the *Rhizophora*, and that of the Health Department who are concerned with the *Avicennia* areas, can be pursued without a conflict of interests, and even to their mutual advantage.

The first bunds at Aberdeen were made with hand labour, at a time when labour was scarce, with the result that progress was slow. During the Agricultural Department's empoldering scheme at Maswari, it was found that the cost of bund building was 7*d.* per cubic yard of material handled and worked out (Macluskie, 1943). In the present anti-*melas* schemes the cost worked out by the Irrigation and Drainage Department is 2*s.* 6*d.* per cubic yard. In small reclamation schemes hand labour is more satisfactory, but on a larger scale the value of excavating machinery for this type of work was amply demonstrated at Wellington. When the reclamation of Wellington orchard was planned, two mechanical excavators (Pl. IV, fig. 1) recently brought to Sierra Leone were used. During the initial stages the African drivers were not thoroughly familiar with their machines, but later the performance of the machines was excellent, and the whole bund over a mile long could have been completed in good time if the excavators had not been withdrawn for more urgent rice swamp reclamation work elsewhere. No estimates of cost by this mechanical method are yet available, but its advantages in speed and efficiency make it the obvious method of reclaiming other large breeding areas in West Africa.

The Extension of *melas* from Coastal Districts inland.

If we look at the map of Freetown estuary (Map 4), it is seen that the main *Avicennia* orchards and breeding grounds of *melas* form a semicircle round a part of the estuary where conditions for the formation of large tracts of *Avicennia* mangrove have evidently been at an optimum. In a previous section it was pointed out that the Bunce River from Hastings to Waterloo is characterised by low numbers of *melas*, and that the Rokel River shows a distinct fall in *melas* density at Tassoh and Pepel. Our studies on the breeding places of *melas* show that this species makes use of fresh water pools on land only to a very limited degree, and that it is restricted to mangrove regions and to a fairly narrow coastal strip.

The estuaries of some rivers are tidal and salty for long distances inland, and a broad mangrove belt may extend upstream to parts of the river which are fresh for many months of the year. In Freetown estuary, salty conditions exist all the year round, the water flooding the *Avicennia* seldom falling below 30 per cent. sea water in the rainy season. But in two other smaller estuaries the seasonal changes were much greater, and therefore offered better opportunities for studying the factors limiting the distribution of *melas*.

At Maswari, south of the neck of Sierra Leone Colony, there is an extensive mangrove region, with a very large *Avicennia* orchard on the estuary of the Ribbi River (Map 3). At the edge of this orchard, there is a reclamation scheme for rice growing by empoldering, and there is a plan to extend this scheme and reclaim in time most of the flat *Avicennia* and *Paspalum* swamp. In the present investigation the main interest in Maswari has been to study the breeding of fresh water *gambiae* in the reclaimed rice polders. Although the breeding places of *melas* were not investigated, useful information about its incidence could be gained from adult catches in houses.

These catches were made in the villages of Maswari and Mabangawilli and in a watchman's house between the two villages. After sorting out the 4-banded *melas*, the 3-banded mosquitos were identified by egg characters. The results are shown in Table X.

Table X.

Record of adult catches in houses of Maswari and Mabangawilli villages from July, 1943, to February, 1944.

Date	Number of adults	4-banded *melas*	Total *melas*	*gambiae* type	Per cent. *melas* in catch
					Per cent.
20.vii.43	152	0	11	141	7
6.viii.43	125	0	54	71	43
17.ix.43	150 (56)*	11	42	108	28
12.x.43	53	3	3	50	6
9.xi.43	72	6	8	64	11
25.i and 3.ii.44	148 (58)*	20	144	4	97

* The numbers in brackets were samples on which identifications were based.

From these figures it is seen that during the rainy season *A. gambiae* is the dominant mosquito, and that the number of *melas* is very low by October. With the progress of the dry weather, conditions for *A. gambiae* became more and more unfavourable, until finally it only makes up a small fraction of the catch, which now is almost entirely *melas*. The total number of *melas* was high in January and February, but by March only a few Anophelines could be found in these villages, and it was evidently an off-season for both species. Without more complete figures it is difficult to interpret these findings, except that the low figures for *melas* in October and November are related not so much to the heavy rainfall as to the freshening of the creek water which reaches a maximum towards the end of the rainy season. In the orchards round Freetown conditions in the rainy season become more and more unfavourable for *melas*, but the numbers still remain high in October and November all round the estuary. At Maswari the unfavourable effect of the rainy season is much more marked, reducing *melas* to very low numbers. From this it seems that even in a suitable *Avicennia* orchard extreme freshening of the tide and creek water by the rains may produce a decrease in numbers of *melas*, comparable to that at the end of the dry season.

Another interesting fact that emerges from these house catches is the very variable percentage of *melas* which are 4-banded. On 20.vii.43 there were no 4-banded adults caught, but egg identification showed that 7 per cent. of the Anophelines were *melas*. On 6.viii there were again no 4-banded adults, but the proportion of *melas* in the catch was now 43 per cent. In all catches at Maswari 15 per cent. of 262 *melas* were 4-banded, compared with 37 per cent. of 731 *melas* recorded at Wellington.

The Great Scarcies River rises in French Guinea, and for a length of about 50 miles forms the north-west boundary of Sierra Leone, entering the sea about 30 miles north of Freetown. It is tidal as far as Kambia, over 30 miles from the mouth, and in the dry weather salty conditions extend as far as Rokupr, about 16 miles from the mouth. This river offers a good example of estuarine conditions extending far inland away from the coast, and shows particularly well the extent of *melas* distribution inland. Throughout the tidal section of the river, the high tides spill over the low banks and flood a great area of flat ground. Much of this flat ground was formerly *Rhizophora* mangrove, but it has been cleared for rice cultivation so that now the Scarcies is the biggest swamp rice growing district in Sierra Leone (Glanville, 1930). Clumps of *Rhizophora* have been left along the river bank (Pl. I, fig. 1), and they extend up the river well beyond Rokupr, showing how extensive the original mangrove swamps must have been.

From July to November most of the river is fresh at all stages of the tide, but in the dry weather salty conditions extend further and further up the river. Samples of river water collected at the beginning of June, 1943, probably represent the highest salinity reached at different places, and are shown in Table XI.

The total catches at these three places, for all seasons of the year, are shown in Table XII.

TABLE XI.

Salinities of river water in the Great Scarcies, June, 1943.

Place and date	Distance from mouth of river	Per cent. sea water	
		High spring tide	Low tide
Katima, 4.vi	6 miles	43	—
Rosino, 2.vi	12 miles	28	14
Rokupr, 2.vi	16 miles	15	7

TABLE XII.

Total *Anopheles* (*gambiae* and *melas*) caught on the Great Scarcies at all seasons, May, 1943 to February, 1944.

Locality	Total catch	*gambiae*	*melas*	Per cent. *melas*
Katima	344	271	73	21
Rosino	205	203	2	1 (approx.)
Rokupr	639	639	0	0

TABLE XIII.

Anopheles caught at Katima, Great Scarcies River, at different seasons of the year, 1943–44.

Date	Total *Anopheles*	*melas*	Per cent. *melas* in catch
8.vii.43	108	26	24
10.ix.43	46	0	0
26.xi.43	67	8	12
17.ii.44	123	39	31

From Table XII it is seen that *melas* has not been found at Rokupr, which is a pure *gambiae*-type area. *Melas* has been recorded at Rosino in the dry weather, and 1 per cent. is an estimate of its proportion. Rosino is evidently the extreme limit of *melas* extension up the river. At Katima *melas* becomes conspicuous, and an analysis of the catches in that village is shown in Table XIII.

These figures show that in Katima the proportion of *melas* in the catch varies considerably, being lowest at the end of the rains, and highest in the dry weather. The general resemblance to the Maswari figures is evident, and seems to show that in both places the heavy rains and the freshening of the creek or river water impose a severe check on *melas* breeding. The Scarcies figures also show that even where brackish conditions extend up the river in the dry weather, the distribution of *melas* is limited by the absence of suitable breeding places such as *Avicennia* swamps.

It is interesting to note that Katima, where *gambiae*-type and *melas* are both abundant, has a notorious reputation among the Temnes and Susus on the river as " the place where God first made mosquitos ". Katima is only a mile or two from the untouched mangrove belt, but there is a small *Avicennia* orchard beside the village. When visited in June the flat rice land round the village was covered with rice stalks rotted by the salty water ; despite innumerable salty pools, no larvae were found there or in the *Avicennia*, although visited at a suitable stage of the spring tides. Nothing is known about the *melas* breeding places responsible for the adult catches.

The Scarcies is considered again later in this report, under the section on *A. gambiae* in rice fields (page 234).

Infectivity of *A. melas*.

Up to 1941, the specific status of *melas* was ill-defined, and its rôle as a malaria vector uncertain.

Barber and Olinger (1931) had found infections among 4-banded melanic forms of *gambiae* in the Lagos area, and they were evidently dealing with *melas*. In the Freetown area, Blacklock and Wilson (1941) and Blacklock, in an unpublished paper, found four sporozoite infections among 74 " var. *melas* "—presumably 4-banded—on the Bullom Shore, and considered that the high infection rate both of malaria parasites and of *Microfilaria* was of considerable importance for West Africa.

On the other hand, Mackay (1938) found no infections in " var. *melas* " in Dar-es-Salaam, but did not state the number of dissections, or the criteria for identifying *melas*, although it is probable that he was dealing with 4-banded *melas*.

In the present investigation the discovery of the egg characters established the identity of *melas* as a separate species, distinct from *A. gambiae*, and it was decided that the time was ripe for a re-investigation of the subject of infectivity.

An arrangement was made with Lt.-Col. Tredre of the 5th Malaria Field Laboratory whereby examination and dissection of material collected by hand catches during the course of my own investigations was undertaken. Nearly all the mosquitos were collected at Wellington—about eight miles east of Freetown—where *melas* was the dominant Anopheline, and supplies were delivered to the Malaria Field Laboratory about twice a week throughout the year. The 4-banded forms could be dissected as soon as the blood digested, but the 3-banded forms were only dissected when their identity had been established by egg identification. During this rather laborious but necessary procedure, many mosquitos died before they could be dissected, and as a result over 2,000 mosquitos had to be supplied to give material for the 1,000 dissections aimed at. In the driest months of the year, March and April, *melas* adults were very difficult to find, and the numbers dissected are scanty compared with other months. A detailed report of the dissections is being prepared by Lt.-Col. Tredre. For the present purpose it is sufficient to summarise these as follows :—

Out of 1,000 glands examined, 42 or 4·2 per cent. were positive.

Out of 931 stomachs, 44 or 4·7 per cent. were positive.

The total infection rate for stomachs and/or glands was 69 out of 885, or 7·~~3~~ per 8
cent. Infections were found in every month of the year except January (the first

month of observations when some infections in the 98 dissections may have been overlooked), and April when *melas* adults were so scarce that no dissections were made. There was no significant difference between the sporozoite rate of 4-banded *melas*—4·5 per cent. of 423 dissections, and 3-banded *melas*, which was 4·2 per cent. of 452 dissections.

The high sporozoite rate of *melas* in conjunction with the high population of adults near the breeding grounds in the Freetown estuary leaves little doubt about the important part it must play as a malaria vector.

Breeding Places of *A. gambiae* in the Freetown, Kissy and Wellington Areas.

Breeding Places in Rainy Weather.

Freetown. Observations in Freetown and outside soon showed that one of the most striking features of *A. gambiae* breeding in the rains was the large number of exposed pools and puddles which appeared to be suitable breeding places, but in which *gambiae* larvae were seldom found. Furthermore, in the comparatively few pools which were selected by this species, larvae were recovered regularly, and usually in large numbers. This observation is not new, and in fact was one of the first findings in Freetown by Ross, Annett and Dutton in August and September, 1899. Their report, which only came to hand after I had been in Freetown for two months, describes the breeding places in the rainy weather in a way which agrees so closely with my own observations that it is obvious the problem has remained fundamentally the same during the last 45 years at least.

In Freetown during the rains one has to look very carefully to find the important breeding places. Innumerable rain-filled pools in laterite in the Brookfields slopes, at the west end of Freetown, were found to be practically free of *gambiae* larvae. Brookfields village itself has a mass of harmless pools and puddles, in among which one would suddenly come across the odd shallow pool swarming with *gambiae* larvae. Many of the negative pools and puddles differed in no obvious way from those that were very suitable, and at the same time very few of those pools could be dismissed confidently without first closely examining them.

The importance of this feature of *gambiae* breeding in the rains was not lost on Ross, but as his observations were limited to Freetown, and only to one season of the year. he refrained from making any statements or generalisations about conditions outside Freetown. Our own observations have extended much further, and they show that the same feature is evident in almost every type of ground on which *gambiae* breeds in the rains. The importance of these few pools in which such dense breeding occurs can hardly be over emphasised, as their recognition forms the basis of most malaria control work.

In many places it would be more correct to say that dense breeding is restricted to the occasional group of puddles, rather than a single pool. This is particularly applicable to boggy ground where most of the surface water may be negative, with breeding restricted to a small patch a few feet or a few yards square, within which every puddle swarms with larvae.

No attempt was made to search every part of Freetown thoroughly, but one of the worst breeding places or rather breeding grounds we found was at Kline Point. Within quite a small area very dense breeding was found in every shallow pool and puddle, particularly on the level ground alongside the railway, between the sleepers, and on a levelled patch with numerous flooded lorry wheel ruts. Unusually large numbers of full-grown larvae and pupae were found in these puddles. The puddles were on bare earth or mud, shallow, with a few tufts of grass, and containing warm water. If there was no rain for a day or two, they were liable to dry up, and as will be described later this was one of their dangerous features. Being entirely dependent on rainfall they dry up very quickly at the end of the heavy rains in October. The shallow pools alongside the railway are identical with those illustrated in Ross's report (1899, page 18, plate 5) and have probably existed almost unchanged, each rainy season, from the time the railway was built.

This breeding ground, discovered by my African assistant, remained unknown and untreated for many weeks in August and September, 1942, despite its important position near the troopship anchorage, and offers a striking example of the necessity for rigid inspection and supervision to ensure efficient anti-larval work in Freetown. Dense breeding was found on the same ground in August of the following year, but was promptly dealt with by the mosquito control department, under new management.

A similar type of breeding ground was found by Blacklock, along the same shore, where a freshly made cutting for a lighter slipway had innumerable flooded footprints, with several hundred larvae and many pupae. In this type of soil constructional work and building operations tend to extend the regular breeding grounds, and to create new problems at every turn ; a constant watch must be kept on such places during the rainy season.

These shallow pools which are most dangerous are dependent on rainfall, and they tend to dry up during the odd dry periods in the rainy season. Eggs of *gambiae* are still laid in these shrinking pools, even in those that dry up on the following day. However, laboratory experiments show that in the damp mud left at the bottom, eggs can remain viable for at least six days, and young larvae for two days. A pool which had been dry for two days was flooded by rain overnight ; on the following morning it was found swarming with young larvae. This means that even if such pools dry up every three or four days it is not sufficient to check breeding. Full-grown larvae are more susceptible to drying up, but after the breeding place has dried up they can still be found alive in the damp mud several hours afterwards. They need only a slight film of water to survive much longer, and pupae are still capable of emerging in damp mud.

In such a breeding ground the pool that has just dried up may be ignored by the inspector, even though a visit on the following day, after rain had fallen, would reveal the new pool with full-grown larvae and pupae. Another factor that makes this type of pool so important is that as one approaches the puddles, all the larvae disappear from the surface, and even remain inert and hidden in the mud at the bottom of the dipper. The careless inspector, seeing nothing in the water or in his dipper, may pass on before the larvae begin to appear on the surface again.

Kissy. In Freetown and its vicinity many of the shallow pits or pools of clear sun-lit water in bare laterite are negative in the rainy season, and this is particularly noticeable on sloping ground. More detailed observations on such pits were carried out in Kissy during the following rainy season, in 1943.

At that time the observations were seldom upset by oiling, and there were many places where effective anti-larval control of *gambiae* was absent. It should be pointed out that these ideal conditions, *i.e.*, from an experimental point of view, ceased to exist shortly afterwards when the reorganised malaria control extended to this area.

In old laterite pools, seldom more than 2 or 3 feet square, with some grass and other vegetation growing in them, larvae were seldom found, a small proportion of about 1 in 50 of the pools being breeding places of *gambiae* in the rains. In the odd pool, however, the number of full-grown larvae and pupae was often large. The positive pools were not noticeably different in appearance or vegetation from the negative ones. Egg collections made in these old pools were nearly all negative, but the odd pool, not necessarily the one with larvae, produced many eggs. There is evidently a certain amount of selection by the female when she is laying her eggs, but this is not sufficient to determine the breeding place. Of the pools in which eggs are laid only a few will be suitable for larval development, as the pool may be washed out or dry up very quickly, depending entirely on weather conditions after the eggs are laid.

At the other end of the same bare laterite slope, numerous new pits were being dug, during July and August, in order to get laterite for army construction work. Nearly all of these flooded little holes and pits, scattered over the surface of the ground, were important breeding places ; many swarming with full-grown larvae, most of them *gambiae*, with a few *rhodesiensis*. The breeding continued in these new pits and holes right through July, August, and September. In the new pits, up to five weeks old, out of 43 examined 38 were positive for *gambiae*, 15 of them with heavy breeding, containing from 30–60 larvae each. Whereas, in 31 old pits in laterite, in the same part of the field, only a few young larvae were found in a single pit. The new pits seemed to contain a little more laterite soil than the old ones, but whatever the reason for the choice they were evidently breeding places of the first importance.

In the laterite of Kissy flats many of these important, rain-filled, breeding places are quite untouched by the drainage schemes, and at that time new breeding places were constantly being created by unrestricted digging of laterite by the villagers.

At the other end of Kissy, several very bad breeding places were found at this time in the Africanus Road area, and alongside the new road which had cut across the drainage slope and created innumerable pools which had to be inspected carefully to find the few pools which produced most of the larvae. In one hour's survey in this limited area between the railway and the new road, 11 major pools were discovered from which 131 *gambiae* and 4 *rhodesiensis* were collected.

The importance of these isolated pools and their cumulative effect was well reflected in house catches in the Africanus Road area at the end of the heavy rains. Hand catches in the first week of October, 1943, gave the following results :—

Rooms searched.	*Rooms positive.*	*Total gambiae.*	*Room index.*
77	26	125	1·6

In 1931 Gordon and others found an *A. gambiae* room index in Kissy of four in September, falling to less than one in October.

Both indices are very crude, but they at least have in common the fact that the mosquitos were caught by the same method, hand catching. House spraying by the Civil Health Department and by the Army Malaria Unit has shown that the Anopheline room index in Kissy has fallen off considerably in the last two years,* but this striking decrease is almost entirely due to the fall in numbers of *A. funestus*. Although there has been a great deal of anti-malarial activity in Kissy in the last few years, the crude hand catches recorded above suggest that the numbers of *A. gambiae* in 1943 were not very different from those in 1931. From what we have seen of the type of breeding place most dangerous in the rainy season, and occurring on the flats between Kissy village and the railway, this is hardly surprising. It is true that many new breeding places have been created here during the war by building and road construction, but it still remains obvious that the attack on the breeding places of *gambiae* was not directed primarily against the comparatively few pools in which continuous dense breeding occurred right through the rainy season.

Since these observations came to an end, in September, 1943, the picture has changed completely, and anti-*gambiae* work is now being carried out on the sound principle of making the main job the destruction of the larvae and the elimination of their proved breeding places.

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* As a result of measures following Blacklock's recommendations.

Wellington. Wellington village has already been described as mainly a *melas* area, as compared with Kissy which is almost entirely *gambiae.* Wellington is also particularly interesting in that it marks the beginning of a belt of low *gambiae* incidence, stretching from the west end of the village to the Orugu River, although the effect of this is masked by the high incidence of *melas* throughout that stretch.

This belt was completely uncontrolled when this investigation started in July, 1942 ; nevertheless the greatest difficulty was encountered in finding breeding places to account for the high catches of adults in the houses of Wellington, Coldbath and Kola Tree villages. We now know that most of these adults were *melas*, the actual number of *gambiae* being low.

Just east of Wellington there are great laterite flats which collect numerous pools during the rainy weather. They differ from those of Kissy, however, in having the surface fairly even, with few pits or holes, and also in that the laterite is usually barer than that of Kissy flats. Small pits dug in this laterite to provide experimental breeding places were mostly ignored by the mosquitos, and in the very few cases in which young larvae were found, development was interrupted by flooding on the one hand and by rapid drying of the pits on the other. In fact, the rapidity with which the flooded flats dried up after one or two days without rain must play a big part in rendering the area as a whole unsuitable for dense breeding.

This area is also interesting in that there is only a negligible amount of *gambiae* breeding in the perennial streams, east of the Rekupa stream, in the dry weather, and that includes the two perennial streams flowing through Wellington village itself.

In Wellington village, which was completely uncontrolled during this investigation, there are numerous laterite pits and hollows in the ground, as well as in blocked and derelict drains. During the heavy rains very few of these pools produce *gambiae* ; but in the early rains, principally in the month of June, there is a short period of intensive breeding, which does not occur at any other time of the year. Larvae appeared in some of these pools in the latter part of May, but the rainfall was too intermittent to prevent the pools drying up completely between showers. But by the middle of June a flat area, about 100 yards square, round the old market place at the east end of the village, had become a main breeding ground. Within this area larvae were found in practically every pool, particularly large numbers being found in small rain filled pools between sweet potato mounds. At this time adults of *gambiae* and of *melas* were taken in almost equal numbers in the houses (Table VI, p. 202), a proportion that occurred in no other month of the year.

This period of dense breeding, when every pool within this area was dangerous, only lasted a few weeks, and breeding practically disappeared with the heavy rains of July.

Protectorate. The types of breeding place used during the rains by *gambiae* in the Protectorate are exemplified by conditions at Rokupr on the Great Scarcies. These will be described fully under that heading, but for the present purpose the point to be emphasised is the restriction of dense breeding of *gambiae* to comparatively small and limited breeding grounds during the rainy season. In thousands of acres of flooded and swampy country, dense breeding is restricted to the swamp edge zone, and only to very limited parts of that zone. Within these small breeding grounds every pool and puddle may produce *gambiae.*

The problem is fundamentally the same as that of Freetown during the rains, control depending on careful inspection, and being seriously upset if the dangerous breeding patches are overlooked.

Breeding Places in Dry Weather.

In Freetown there is a fairly distinct dry season from about the middle of November till the middle of April, the rainfall in the four months of December, January, February and March totalling less than 3 ins. in a 50-year average. These dry months are followed by a period of intermittent rain from about the beginning of May till the middle of June. The heavy rains start about the end of June or the beginning of July.

From the Malaria Field Laboratory figures of 1943 (Table V, p. 201) referring to catching stations between Aberdeen and Waterloo, it is obvious that the number of *gambiae* caught in control houses each month was roughly ten times greater in the June-July period than it was in the dry months of the year. In some places, such as Kissy village, the disparity is even greater, giving a definite off-season when adults are extremely difficult to find in houses. From these figures alone, it is indicated that in the Colony at least breeding of *A. gambiae* in the dry season is of minor importance as compared with the peak period in June and July of the rainy season.

Unfortunately *gambiae* does not lend itself to generalisations, even within Sierra Leone. We have seen that while *gambiae* has a definite off-season in the dry weather at Maswari (Table X, p. 219), yet on the Great Scarcies adults are present in large numbers at all seasons of the year.

There are obviously local differences according to the type of country and available breeding places. Even within the mountainous Colony itself, conditions in the dry season vary from place to place, and while the statement about adults being roughly ten times more numerous in June and July than in the dry weather applies to the Colony as a whole, it might be misleading if one happened to be interested only in one limited part of the Colony. The part of the Colony naturally claiming most attention is Freetown, and as it happens the conditions of *gambiae* breeding in Freetown in the dry weather differ markedly from conditions in the rest of the Colony, and it is this difference that has given rise to misundertanding and divided opinions, particularly about the importance of perennial streams.

In the dry weather of 1943, from January onwards, a detailed survey of several perennial streams, all outside Freetown, was carried out. Most attention was paid to the Congo and the Orugu Rivers, but all streams between Freetown and Hastings on the south side of the estuary were examined from time to time. Particular attention was paid to numbers and distribution of full-grown *gambiae* larvae and pupae, and their possible bearing on control measures (Map 7).

In these streams we are dealing almost entirely with *gambiae*-type ; 16 egg collections from four streams between January and April producing

A. gambiae-type	582	*A. melas*	0

A brief summary of the main features of breeding in these streams is given below.

Congo. (Pl. VI, fig. 4.) This perennial stream forms the western boundary of Freetown and flows in a rocky and boulder-strewn stream bed roughly from Hill station to the estuary near King Tom. There are comparatively few houses alongside this stream, and it is not considered a part of Freetown proper. *Gambiae* larvae were found here in a survey by Davey (1938), and it was evidently considered important enough to have a dam and sluice gates installed at the upper part of the stream, with a view to control by flushing.

In 1941 a detailed survey (unpublished) was made by Ribbands and Slater, and the larval distribution of all Anophelines recorded and mapped. Among other things, they showed that *gambiae* breeding was restricted to a comparatively short stretch in the lower part of the stream, from just above the old railway bridge to just below Brookfields Bridge. The upper part of the stream was free of *gambiae*, although many harmless Anophelines were common there.

In the present investigation, the findings of Ribbands and Slater have been confirmed, and it soon became evident that even in this stretch of the river, breeding of *gambiae* was limited to comparatively few pools and pockets, which are dangerous because of the dense breeding that may occur in them. For example, a stretch of two or three hundred yards was found negative for *gambiae*, with no sign of scattered breeding along the edges, but the presence of a single pool swarming with larvae gave the whole stream a distorted reputation. In that stretch of river to which *gambiae* is limited not more than half a dozen such pools have been found, and their elimination presents no great difficulty. In some of these small pools, however, the numbers of full-grown larvae and pupae are high, and if they are overlooked and unchecked, breeding may continue for weeks on end, resulting in the high figures that are sometimes recorded for adults caught in the nearest isolated house.

The important breeding pools are usually quite small ; a shallow rock puddle with dead leaves, or a little side pocket dammed with a plug of decaying straw. The number of such breeding places in the lower part of Wilberforce stream, where it flows into the Congo, was always greater than in the whole Congo itself, and in a pool a few inches square it was possible to find 40–50 larvae on each visit. Thirteen visits were made to these streams between the end of December and the end of March, and throughout that whole period, some of the pools were found to be producing full-grown larvae and pupae continually.

Any control scheme which treats the river as a whole, while ignoring or overlooking these few important pools, is likely to give disappointing results.

Orugu River. (Map 7 ; Pl. VIII, figs. 1–3.) The Orugu River runs from the hills behind Hill station down the Orugu valley to the estuary at Jui. In the dry weather *A. nili* is the important vector. The river itself is described in more detail later in this paper (page 246). In the long course of this stream only odd larvae of *gambiae*, 9 in 11 visits, have been found (Table XIV), and the Orugu is evidently of minor importance as a dry weather breeding place of *gambiae*. In the houses of the two large villages of Regent and Charlotte on this stream, *gambiae* is overshadowed by *nili*, and random collections suggest that even in the rainy season *gambiae* is scarce in these two villages.

TABLE XIV.

Total larvae from the Orugu River, in January to June, 1943, and January to March, 1944.

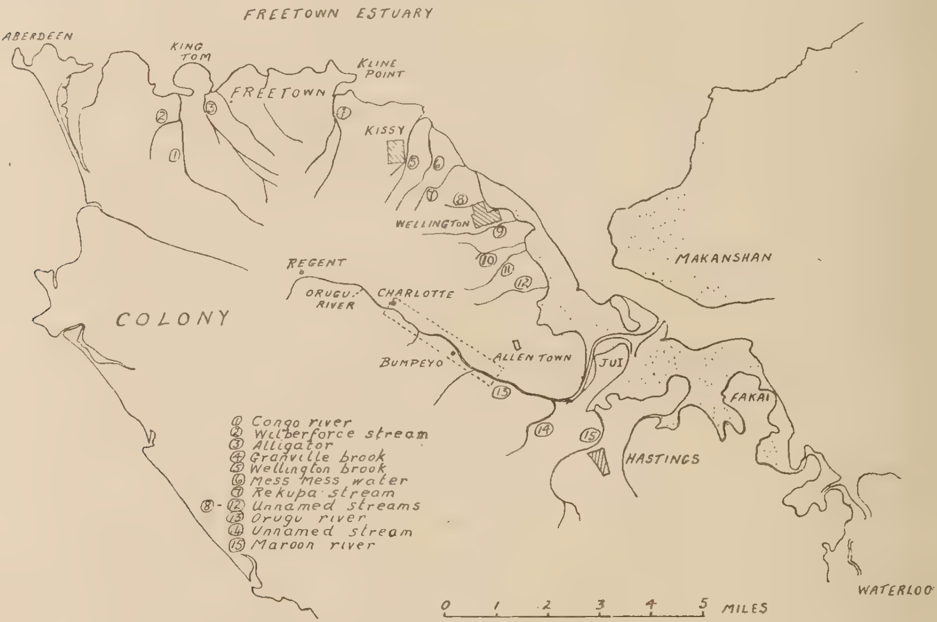
A. nili	155	Also *A. coustani*, *A. obscurus*, *A. barberellus* and *A. moucheti*.
A. rhodesiensis	166	
A. hancocki	46	
A. freetownensis	34	
A. hargreavesi	18	
A. gambiae	9	
A. funestus	4	

Wellington Brook. This is the stream just east of Kissy village (Map 7 ; Pl. VI, fig. 3), and from its position would seem the obvious dry weather breeding place for *gambiae* in this district. This again is, however, a minor breeding place of *gambiae*, the numbers of larvae recorded being much lower than in the Congo. The observations about breeding places in that stream apply equally well here, except that only one or two pools of any importance have been found in six visits.

While most attention was paid to this perennial river itself, collections were also made in a few sweet potato plots beside the river. The total number of *gambiae* larvae caught in all collections was 108 for the potato plots, and 55 from the Wellington Brook. Furthermore, breeding was found in potato plots above the main Kissy-Wellington road, a part of the stream where *gambiae* was never found.

This stream is evidently of minor importance, and further evidence to show how much more important the sweet potato patches are will be described later.

Rekupa Stream. (Map 7; Pl. VII, figs. 1, 2.) This is not a perennial stream, as the lower part dries up partially or completely in the dry weather. While in the process of drying up, it can be a very bad breeding place due to the fact that the laterite bed is hollowed out into innumerable shallow pot holes with pools of water in which large numbers of *gambiae* larvae are found. Dense breeding is liable to occur in a long stretch from the main road downwards to the waterfall at its mouth. In some of the pools 100 larvae have been taken in one dip. This stream will be described later under the heading of experiments on flushing.


FREETOWN ESTUARY
ABERDEEN
KING TOM
FREETOWN
KLINE POINT
KISSY
WELLINGTON
MAKANSHAN
REGENT
ORUGU RIVER
CHARLOTTE
COLONY
BUMPEYO
ALLEN TOWN
JUI
FAKAI
HASTINGS
WATERLOO
① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩ ⑪ ⑫ ⑬ ⑭ ⑮
① Congo river
② Wilberforce stream
③ Alligator
④ Granville brook
⑤ Wellington brook
⑥ Mess Mess water
⑦ Rekupa stream
⑧-⑫ Unnamed streams
⑬ Orugu river
⑭ Unnamed stream
⑮ Maroon river
0 1 2 3 4 5 MILES

MAP 7. Freetown and neighbouring parts of the Colony showing streams investigated in the dry weather. Mangrove areas stippled. Area of *A. nili* predominance in Orugu valley enclosed by broken line.

The other streams between Freetown and Hastings have been visited at various times, but none of them is considered of any great importance as *gambiae* breeding places.

The conclusion seems to be that in the general scheme of control most perennial streams outside Freetown occupy a position of minor importance, and that in the few streams where breeding does occur regularly, the problem is not one of diffuse breeding along the river, but of the odd pool with dense breeding. A semi-perennial stream like the Rekupa stream can be dangerous if the bed encourages pool formation while the stream is drying up, or when the early rains fill the pools for some time before the stream starts to flow.

Streams in Freetown. The perennial streams in Freetown have received a great deal of attention (Blacklock, 1921, Blacklock & Evans, 1926), and it is evident that they cannot be dismissed as lightly as the streams outside Freetown. At the same time there seems little doubt that these streams have claimed undue attention in the past, to such an extent that many have been led to believe that their permanent control is the most important anti-malarial scheme in Freetown. Of the two main streams, Nicol Brook and Alligator Brook, attention has been limited in this investigation to the lower part of the Alligator at Kroo Bay. In the dry weather early in 1943 a considerable amount of breeding was found here. The worst breeding places were isolated pools, usually separate from the main stream, some of them swarming with hundreds of larvae. Many of them remained untouched or overlooked for weeks on end, and their continual production of mosquitos was reflected in high catches in Kroo Bay houses. The lower part of the stream was canalised at this time (Pl. VI, fig. 2), and there were very few larvae in the main stream. In the following dry weather, 1944, very extensive breeding was found here by Drs. Turner and Walton, in charge of malaria control. Swarms of larvae occurred along the edge of the main stream, in backwaters among stones protected from the main current by a thick mass of green alga. The water in this stream is very foul in the dry weather, offering a striking contrast to the rivers outside Freetown, and larvae can be found abundantly in filthy, evil-smelling pools.

These Freetown streams are undoubtedly important breeding places in the dry weather, and in the early rains when pools are produced on the flat ground near the main stream, but their control is only one of many schemes in Freetown. There is frequently a tendency to overestimate the importance of any Anopheline dry weather breeding place ; in the dry weather the available water is greatly reduced, larvae are more concentrated, and the breeding places—limited in number—become well known. It is a common experience in many countries that larvae can be found more easily in the dry weather, when the number of adult mosquitos is at its lowest. Furthermore, it is commonly believed, and somewhat naturally, that the denser the breeding in the dry weather the greater will be the rise in numbers of mosquitos in the early rains of June. Actually, there is little evidence to show whether this is the case or not. Wellington village, quite uncontrolled in 1943, is remarkable for its scarcity of *gambiae* breeding places in the dry weather. Nevertheless it also exhibits a sharp increase in *gambiae* early in June, reflected both in the breeding places and in the house catches (page 202).

The Nicol Brook and the Alligator are both well known breeding places, and their control is a matter of routine. At present they are only dangerous when careless inspection or faulty treatment by the inspectors in charge has let breeding get out of hand. This can happen in a few days, has done so frequently in the past, and is still liable to do so. It is not necessary, however, to magnify the problem on this account or to consider that it can only be solved by a costly scheme of canalisation, which will leave little surplus money or interest for the hundred and one other problems of anti-malarial work in Freetown.

At the time I left Freetown in April, 1944, the results of strictly supervised routine control measures, carried out by the Mosquito Control Department, were already strikingly evident in the Alligator and Nicol Brook.

Experiments on Flushing. Flushing as a method of controlling stream-breeding Anophelines has been advocated in many parts of the world, particularly in recent years ; and many improved forms of siphon, automatic and hand-operated, have been designed. By 1942 dams with hand-operated sluices had been installed in three streams near Freetown, the Congo Brook, Mess Mess water between Kissy and Wellington, and the Rekupa Stream. As has already been described, the Rekupa Stream has its laterite bed hollowed out into innumerable holes and hollows (Pl. VII, fig. 1), which contain pools in the dry season before the stream finally dries up. This seemed the type of problem that could be controlled by a good flush, and this idea was certainly encouraged when the flush was seen in action. The volume of water released, estimated at 19,000 gallons in the first minute by the Sanitary Superintendent, created a most impressive flood of water, completely washing the stream from bank to bank, and scouring out the pot holes in its course. It seemed as if nothing could survive such a flushing, and as it was carried out twice a week, the feeling of security it engendered is quite understandable.

When the stream was flushed twice a week, on Mondays and Fridays, fourth-stage larvae could be found in the small pot holes by Wednesday morning. On Thursday morning many pupae were collected that emerged on Thursday night, and pupae were again found on Friday morning before the stream was flushed. This was in a part of the stream between the road and the railway, which received the full force of the flush, and it was assumed that appearance of pupae was due to very rapid development in those small pools of warm water with concentrated food supply.

The stream was now flushed every second day, but conditions became worse instead of better. Pools near the edge of the stream that had dried up quickly on previous occasions were now kept flooded and in such a position that the next flush carried larvae from them in among the vegetation at the edge of the stream. As the flush subsided, the larvae began to appear at the edges and gradually found their way back into the pools where development continued. As a result such pools were swarming with larvae on the day following the flush. A further complication of flushing every other day was that vegetation along the edge of the stream, and in the stream bed itself, grew more rapidly and provided endless backwaters where larvae could shelter during the flush.

By this time a second dam had been installed further up the stream than the first one, and the experiments were now continued under conditions that appeared ideal for flushing, namely, using a bigger head of water from two dams instead of one, at a time when all the hollowed out pools in the stream bed were already full of water. The two sluices were opened in such a way that the breeding area was swept by a second flush before the first one had started to subside. From a mechanical or engineering point of view conditions were ideal, and the flush as a flush left little to be desired. The results, however, were exactly the same as before, many full-grown larvae and pupae of *gambiae* being found in the stream on the day following the double flush, breeding extending just as far up the stream bed as it did before the flush.

Larvae flushed out of pools in the centre of the stream bed are carried to the slack water at the edge of the stream where they remain at the bottom. An hour or two after the flush these larvae could be seen coming up to the surface at the stream edge, and gradually following the falling water level back to the pools, and thus avoiding being stranded. Experiments in the laboratory have shown that larvae can survive a four-hour immersion under water, and are therefore unlikely to be drowned by the flush.

The unavoidable conclusion is that flushing is ineffective and even dangerous as a control measure against *gambiae*, particularly when it is borne in mind that this method of attack more than any other is liable to produce a false feeling of security.

From what has been said about breeding in the Congo stream, it is obvious that that stream would be even less well adapted for flushing, and affords another example of a control scheme directed against the stream as a whole, and which does not take into account the nature of the breeding places it is intended to control.

In view of the failure of flushing in the Rekupa Stream, the natural drying up of the stream bed was accelerated by the Health Department, who canalised the centre of the stream, and filled in with concrete the hollows and potholes alongside (Pl. VII, fig. 2).

This measure in conjunction with routine inspection for the occasional pool at the beginning and end of the rainy season, offers a much simpler and more efficient means of control.

The water banked up by the dams is a useful reservoir in the dry weather, and the periodic release of this water as it becomes foul is unlikely to have any harmful effect on that part of the stream bed treated as described above.

Sweet Potato Plots.—In the account of dry weather breeding in Wellington Brook, it was seen that more larvae were found in the few potato plots alongside the stream than in the stream itself. These observations have been extended to show that, outside Freetown, sweet potato plots are responsible for more *gambiae* breeding in the dry weather than any other single type of breeding place. How dangerous they are depends on local conditions, which vary considerably, and according to the time of the year. Between Kissy and Wellington they are common along the swamp edge outside the mangrove zone (Pl. V, fig. 5) and near streams which can be used to supply the necessary irrigation water. The water necessary for cultivation is supplied either by digging the mounds so near the swamp edge that the hollows between the mounds tap subsoil water, or by diverting water from a stream or a spring as is necessary on higher ground, or simply by watering the plots regularly. All methods are used in different parts of the plots shown in Pl. V, fig. 5.

Throughout the dryest months of the year, there are very few plots that do not contain one or two shallow puddles, particularly suitable for *gambiae*, in which full-grown larvae and pupae may be taken regularly. There are many pools in which breeding is never found, while other plots may have every puddle positive. Like everywhere else, potato plots have to be searched carefully to find the odd pool producing most of the larvae.

As the furrows between the ridges become flooded, new pools appear on higher ground, and the breeding shifts. In Wellington village itself on high ground above the potato garden zone some of the worst breeding places in June, responsible for the peak of adults in that month, were in shallow rain-filled pools between potato mounds at the east end of the village. Similarly, in a fresh water swamp which had been well-drained, sweet potato cultivation between the main drains created little rain-filled hollows in which dense breeding of *gambiae* occurred in August, the wettest month of the year.

The constant creation of new breeding places by wet cultivation near important towns and villages in the estuary is one of those unrestricted activities that makes the work of anti-malarial inspection so arduous and endless. In their brilliant campaign against *gambiae* in Brazil, the Rockefeller Foundation and the Brazilian Health staff found it necessary to prohibit sweet potato cultivation in certain areas, and this example could be followed with advantage in parts of Freetown estuary.

Anopheles gambiae breeding in Rice Fields.

In recent years a striking feature of agricultural development in Sierra Leone has been the great extension of swamp rice cultivation, particularly in the Scarcies area in the north west of the country. With the setting up of an Irrigation and Drainage Department a few years ago, reclamation schemes are already well advanced, and are likely to increase even further in scope in the next few years.

Great areas of estuarine swamps are unsuited for rice growing because they are inundated by tidal water, which is too salty for most or all of the year. Some of these areas are being protected from the high tides by bunds, incorporating sluice gates or tidal flaps which control the water behind the bund. Other areas, although fresh, are too deep and stagnant for rice; drainage of these deep water swamps is offset by the banking-up effect of the high tides, and in order to ensure proper drainage and water control these areas are also being bunded or empoldered in the same way.

At the present moment swamp rice is being grown under such a wide variety of conditions that it is quite impossible to generalise about rice fields and Anopheline breeding, in the way that can be done for large tracts of uniform rice fields in India, Burma and Malaya.

In Sierra Leone much of the swamp reclamation is being carried out in the Protectorate in regions remote from large towns or European communities where malaria control never has been seriously considered. At the same time the possibility of this agricultural work being developed near Freetown Estuary, or near the airfield and sea-plane bases, has been under consideration by the Agricultural Department; it was therefore imperative to have some idea of what effect, if any, this would have on the malaria situation.

In the control of *melas*, large orchards were going to be reclaimed by much the same methods used by the Agricultural Department, and we set out to find if there was any chance of using this reclaimed ground for swamp rice, or whether such a step would merely amount to a *melas* problem being replaced by one of *A. gambiae.* In many parts of the East, rice fields are quite harmless from a malaria point of view, and at the beginning of this investigation it appeared that there might be a chance of this happening in Sierra Leone too.

Before going any further it would be as well to say at this stage that we now know that rice fields can be very dangerous breeding places of *gambiae*, and that this applies also to rice plots in reclaimed *Avicennia* and *Paspalum* swamps. To eliminate *melas* by bunding, and then to make use of the reclaimed ground for swamp rice, without introducing a *gambiae* problem has proved rather an ambitious ideal; and for the moment we must be content to concentrate on the mosquito control, and get that established first and foremost.

The observations on Anopheline breeding in rice fields have been made in two different areas, Maswari and the Scarcies.

Maswari.—This area, south of the neck of Sierra Leone colony, and 35 miles from Freetown (Map 3), has already been partly described (see p. 218). In this part of the coast, the saltiness of the water is the main obstacle preventing swamp rice cultivation in large tracts of tidal flats. At Maswari the Agricultural Department started a scheme in 1938 for empoldering an area of *Avicennia* and *Paspalum* swamp by means of bunds. By 1943, ten acres of reclaimed ground was producing rice, the plots ranging in age from 1 to 5 years old (Macluskie, 1943). From the mosquito control point of view, these plots are particularly interesting, as they almost certainly represent conditions that would arise were similar tracts of mangrove reclaimed for swamp rice cultivation in Freetown estuary. Another important feature is that within the empoldered area there is a further subdivision, by means of smaller bunds, into plots; the bulk of water in these plots is undisturbed by irrigation or flow, resembling closely the rice fields found in large tracts of the Indian plains, and differing strikingly from conditions on the tidal flats on the Scarcies of Sierra Leone.

The plots are quite dry up till the early rains of June, when they are ploughed. In July the plots have been smoothed and transplanting started, although the plots are not completely flooded by the heavy rains till later in the month. By the end of July transplanting is complete (Pl. IV, fig. 6); by October the rice fields are well grown (Pl. V, fig. 3). In November the rice is ripe, ready for harvesting, and although there is still water in the plots, they are drying up rapidly. By January the whole area is completely dry.

Within the same rice plot conditions vary considerably. One end is usually completely flooded by a continuous sheet of water a few inches deep, while the other end may be broken up into innumerable pools. The extent of the flooding varies from day to day according to the rainfall, and several isolated pools with larvae may be joined into a continuous sheet of water by one heavy shower. Under such conditions it is extremely difficult to form an estimate of the relative density of breeding in different plots, or at different times, and as work on rice fields was only one of many projects, we had to content ourselves with rough comparisons based on the total number of larvae collected in a fairly uniform period of time. But one fact was quite definite; *gambiae* larvae were present in all plots, and at all stages of cultivation, through the entire season from ploughing to full-grown rice.

The results are summarised in Table XV.

TABLE XV.

Breeding of *A. gambiae* and other Anophelines in rice plots at Maswari, Sierra Leone. 1943.

Date	Condition of plot	Breeding	Details of larvae collected and identified. Full-grown larvae in brackets.						
			Larvae			Eggs			
			gambiae	*coustani*	*squamosus*	g.	m.	c.	sq.
11.vi.43	Plots ploughed, mostly dry, few pools present	Negative	—	—	—	—	—	—	—
7.vii.43	Transplanting started. Plots partly flooded	Many young and intermediate larvae. None full-grown.	—	—	—	—	—	—	—
20.vii.43	All plots with transplanted seedlings. Flooded after rain into continuous sheet of water.	Many larvae of all stages collected in open water.	—	—	—	71	1	3	—
6.viii.43	Plot with seedlings transplanted 5 weeks before. Continuous sheet of water.	No full-grown larvae ..	28 (0)	—	—	3	—	—	—
—	Large plot with seedlings less than 2 weeks old. Water in innumerable pools (Pl. IV, fig. 6).	Larvae of all stages in nearly every pool.	74 (8)	—	—	34	2	—	—
17.ix.43	Well grown plot. Rice 11 weeks planted. Isolated pools among rice.	Most larvae in isolated pools.	25 (5)	—	—	—	—	—	—
—	Large plot. Rice now 8 weeks old. A continuous sheet of water.	Most breeding along edges of plot.	130 (15)	—	—	12	—	—	—
11.x.43	Well grown plots. Tall rice plants nearly flowering. Continuous water (Pl. V, fig. 3).	Many young larvae ..	2	19	3	8	—	10	6
—	Large plot. Continuous sheet of water. ..	Breeding along edges and in open plot.	35 (6)	51 (18)	—	—	—	—	—
9.xi.43	Rice ready for harvesting. Plots drying up quickly. Several isolated pools among tall rice.	Many larvae in isolated pools.	51 (3)	27 (6)	25 (3)	4	—	3	7
24.i.44	Plots all dry	—	—	—	—	—	—	—	—
		Totals	345	97	28	132	3	16	13

From this table it will be seen that larvae of *A. gambiae* type are practically the only Anophelines present from the beginning of the season till the end of the heavy rains at the end of September. In the period after the rains it is joined by *coustani* in numbers, followed later by *squamosus*, the three being almost equally abundant at the end of the season. From the figures it is impossible to say which stage of rice growing is most suitable for *gambiae* breeding, or even whether isolated pools or a continuous sheet of shallow water is most favoured. Egg collections show that many eggs are laid in the open water of the plots, in water that has been in a continuous sheet for some time. In other cases eggs might have been laid in pools which were shortly afterwards flooded into a continuous sheet of water by heavy rain falling before the collections were made.

Adult catches in the neighbourhood show high figures for *A. gambiae* throughout the rice season (Table X, p. 219), in one case over 140 adults being recorded from one room of a watchman's house beside the plots.

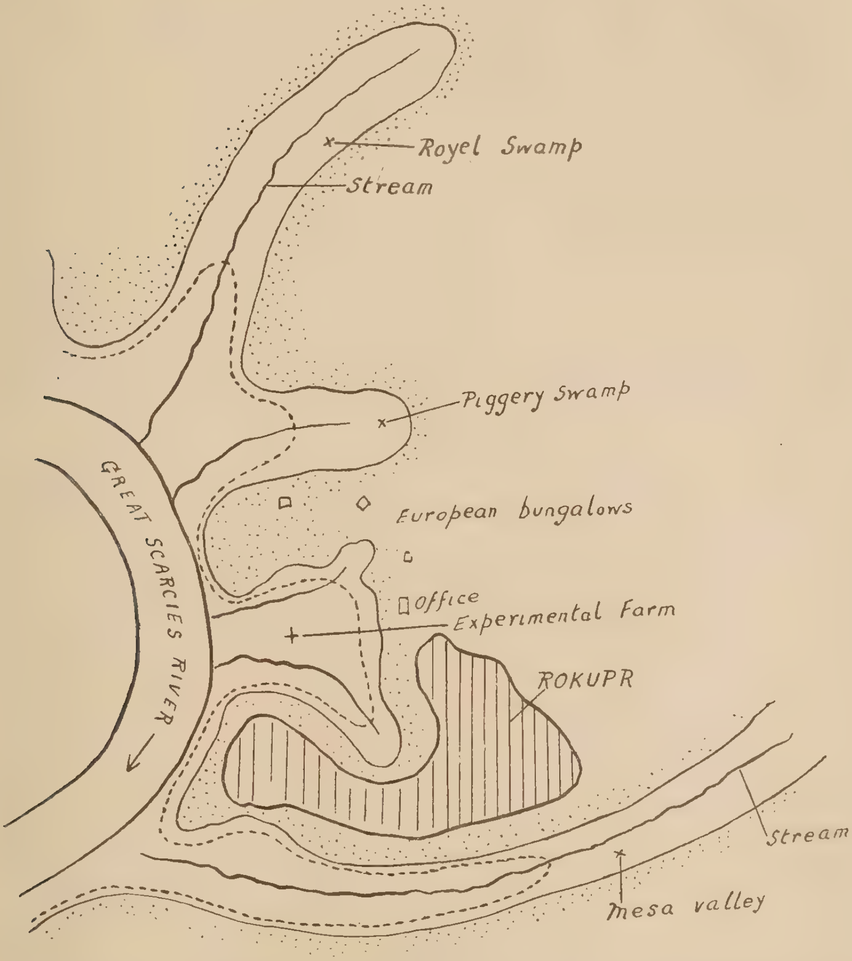
In some countries the dangerous Anophelines breed in rice fields only at certain stages of cultivation. For example, *A. culicifacies* in South India breeds in the early stages of rice cultivation, but disappears when the rice plants become well grown (Russell & Ramanatha Rao, 1940).

There is no sign of this happening in the case of *A. gambiae*, which breeds in rice plots at all stages of cultivation, even in shallow pools among full-grown rice. The capacity of *A. gambiae* larvae for surviving in damp mud, and the existence in Sierra Leone of a long season of heavy rainfall, are sufficient to discourage any attempt at control by intermittent flooding and drying.

The plots at Maswari are in a part of the country saturated with *gambiae* and *melas*, and are several miles from European houses. There is not the slightest question of trying to control breeding in such a place, but what we can do is to profit by this experience and make certain that no breeding places of this kind are allowed to be created near the airfields, anchorage or large European settlements.

The Great Scarcies (Maps 3 & 8). The main features of this region, as well as those particularly affecting *melas*, have been described earlier (p. 219). Most of the rice here is grown on the flat expanse of country on either bank of the river and its creeks. Much of the land was formerly covered by *Rhizophora* mangrove, which has now been cleared for many years. Except at certain neap tides in the dry season, most of the rice land is flooded by the high tide once every 12 hours. The great flat stretches of rice land are not subdivided into plots, and there is nothing to impede the ebb and flow of the tide. The degree of flooding, and the extent of swamp affected by the high tide, varies according to the season of the year, to the type of tide, and to the amount of water coming down the river.

Conditions of salinity, as has already been described, vary enormously, most water at high tide being quite fresh as far as the mouth of the river from July to November. After this the salinity increases slowly, and extends further up the river to reach a maximum about June, as shown in Table XI (p. 220). Near the mouth, *e.g.*, at Katima, the rice fields are flooded by 50 per cent. sea water at high tide in the dry season, a salinity high enough to rot the rice stalks left after harvesting, but not apparently affecting the rice crop of the following season which commences in July. Further down the river, salinity becomes a limiting factor to the further extension of rice cultivation.



Map 8. Rough sketch map of Rokupr and its swamps. The stippling marks the beginning of the high ground above the swamp edge. The broken line marks the extent of swamp flooded by the river at high spring tide. Scale approximately 2 inches to 1 mile.

The whole Scarcies area is notoriously unhealthy, but because of the very small community of Europeans, mostly at Rokupr, there is never likely to be any question of anti-malarial work for the river as a whole. Quite apart from the rice fields, this region is worth investigating as it offers a wide range of conditions, including many common to large areas of the Protectorate, which at the same time are strikingly different from anything occurring in the Freetown estuary.

The Rice Experimental Farm at Rokupr was selected as the obvious centre (Maps 3 & 8). At this part of the river all the villages and houses are built on high gravelly ground between swamps. On this porous soil and well drained slopes there is no natural surface water, even at the height of the rainy season. The ridges slope abruptly down to the swamp edge where there is a fairly sharp transition to swamp land and tidal flat. Much of the swamp is affected by the rise of tides in the river, but here and there are long arms of the main swamp in which the tidal effect becomes less and less obvious, till at the head of the swamp a point is reached well beyond the influence of the highest tides. When this happens conditions are reached very similar to those of the inland swamps of the Protectorate. The longest of these finger-like swamps usually have a small central stream, conspicuous in the dry season, but obscured by flooding in the wet season.

Six visits, each lasting about a week, were made at Rokupr between May, 1943, and February, 1944, covering all seasons of the year.

As the ground used for rice at one time of the year may be used for other crops at another season, the investigation was extended to *all* breeding places of *A. gambiae* in this district. Map 8 shows the different places investigated.

The following swamps received most attention :—

Experimental Farm Area. The outer part of this swamp was flooded by the high tide every 12 hours. Further towards the land the ground was divided into plots, partially or completely bunded. At neap tides these flooded plots were left untouched, giving conditions very like those of Maswari. At spring tides the bunds at that time were not big enough to prevent the whole area being flooded. In all the other village rice swamps outside the experimental farm there were no bunds, and tidal movement was unimpeded.

Piggery Swamp. The outer part of this was affected by tides, but the inner part was like a small inland swamp, with the ground boggy or flooded with stagnant water.

Royel Swamp. This swamp was well beyond tidal influence, and mostly a deep-water inland swamp in the rains. There were two experimental rice plots here, constantly with deep stagnant water and aquatic vegetation through the rice season. The swampy ground dried very slowly in the dry season.

Mesa Valley. A narrow valley influenced by tides in its lower part. The upper part was boggy and swampy in the rainy weather, but not to the same extent as in Royel ; drying up fairly quickly in the dry weather, and leaving a well-defined central stream.

The rice cultivation season follows roughly the same course as at Maswari, except that transplanting is later in starting, except in the experimental farm, and the harvest is not complete till January. From Table XII (p. 220), it is seen that in Rokupr the problem is almost entirely one of *A. gambiae, melas* not extending as far up the river as this. The total *Anopheles* caught in houses in Rokupr for the whole season were as follows : *A. gambiae*-type 639, *A. funestus* 8, and *A. coustani* var. *ziemanni* 3. All the *funestus* were caught in November, when they formed six per cent. of the adult catches in that month. Otherwise the malaria problem seems to be almost entirely one of *A. gambiae.* The larval collections will be summarised after breeding at different seasons of the year has been described.

May–June.

At this time of the year all the village rice lands are still lying fallow, and the even ground is covered with last year's rice stalks, still standing in some places, but in others forming a carpet of decaying straw. Over all this area there are innumerable pools left by the high spring tides and by the rain. Not a single larva was found in any of these pools within reach of the normal high tide.

There were also innumerable pools left by the high spring tides—over ten feet—which occurred in the latter half of May, left undisturbed by later high tides less than ten feet. Most of these pools were negative, but dense breeding occurred in a few places. Dense breeding of *gambiae* was restricted to definite patches of the swamp edge zone, in particular, pools in deeply ploughed experimental plots near the dry land. Within a small area many larvae, including fourth stage, and pupae were found in nearly every pool (Pl. IV, fig. 5) examined. Water was brackish—

8 per cent. sea water—showing that these pools were probably left behind by the highest spring tides, over ten feet. Egg collections produced 21 *A. gambiae*-type.

Between this breeding ground and the dry land, was a belt of sweet potato mounds. In the water between these mounds numerous young *gambiae* larvae were found (Pl. V, fig. 6).

Another main breeding ground was a level patch of " fundi " or Creole Millet (*Digitaria exilis*) in the piggery swamp. This resembles a fallow rice nursery, or a boggy, unkempt lawn, with spongy ground, and surface water limited to numerous very small puddles in among the grass roots. Large numbers of full-grown larvae and pupae were recorded from every puddle over an area of about 100 feet square. This plot is above the highest spring-tide mark, and at this time of the year, breeding is dependent on intermittent showers of rain. With no rain for two or three days, it is liable to dry up completely, when active full-grown larvae may still be recovered from the mud at the bottom of the puddles. With heavy showers, larvae may be flooded out and found in the continuous stretch of water formed outside the fundi plot. As most larvae were about the same stage of growth, the breeding ground was probably created only recently about the end of May.

July.

At the beginning of this month the hillsides, and the open spaces between the houses, leading down to the swamp edge are bright green with rice nurseries. Transplanting has barely started in the village rice lands, which are being brushed (all vegetation cut down), and hoed in preparation for seedlings. The sweet potatoes have all been dug up, and the mounds are now being flattened to make rice plots. The cassava mounds near the swamp edge are being treated in the same way. Fresh water swampy areas, with thick sedge or bog vegetation, are all being cleared in preparation for rice.

Most of the nurseries are on well drained ground with no surface water, but where they occur on flat ground near the swamp edge, with numerous small rain-filled puddles among the seedlings, dense breeding of *A. gambiae* is liable to occur (Pl. IV, figs. 3, 4). Dangerous breeding places of this kind were quite dry in the May–June period.

The wide rice lands affected by the high tides are all negative, although hoeing has created innumerable pools.

The numerous pools formed by flattening sweet potato mounds, and cutting the thick vegetation, are all highly polluted with rotting vegetation, and are negative for larvae.

The flat fundi plot, a dangerous breeding ground at the beginning of June, is now well grown and with the grass 1–1½ feet high looks like a hay field. The surface water is still restricted to small puddles among the grass roots, and from the number of *gambiae* larvae of all stages is evidently still a major breeding ground. Fortunately fundi plots of this type are not common.

The only other breeding places of note in the Piggery swamp, and in the Royel and Mesa valleys, were flooded foot-prints on pathways leading through cassava patches to the swamp edge. Freshly hoed plots at the extreme swamp edge are liable to have numerous small pools with *gambiae* larvae (Plate IV, fig. 2).

At the experimental farm the deeply ploughed plots, breeding *gambiae* early in June, are less broken up and now contain freshly transplanted seedlings. *Gambiae* larvae are still abundant in the small pools, but are not so numerous as before. The area flooded by high tides has extended to include most of the experimental farm plots, which are still quite negative for *gambiae*. The small breeding ground near the swamp edge is reached by the 9·5 foot tide and completely flooded by the 10·8 foot tides later in July.

A. gambiae adults are particularly abundant at this time, 147 being caught inside one bed net at Rokupr on 8.vii.43.

September.

Most of the rice land is now covered with growing rice, much of it recently transplanted. Over the greater part of these rice fields *gambiae* was absent, breeding again being restricted to a few breeding grounds. In some village land beside the experimental farm, *gambiae* was found in small shallow pools among transplanted rice beside the dry land (Plate V, fig. 1). The pools were rain-filled, and contained 30-40 larvae over an area of about 20 yards square each of about 30 pools. Outside this dense breeding ground no larvae were found, even though innumerable suitable looking pools were present. In previous visits this rice patch was given over to sweet potato (Pl. V, fig. 6). Near the breeding ground many *gambiae* larvae and pupae were found in small wash pits (Pl. V, fig. 2) about a foot in diameter, dug to wash the soil from seedlings before transplanting.

Not a single larva was found in the whole experimental farm area, and the fundi plot was now given over to rice and was negative.

Gambiae larvae were found in small pools in a fallow rice nursery at swamp edge. This area was dry on previous visits, but from its appearance had been suspected as a possible breeding ground later in the rainy season. In another fallow rice nursery, flooded to a depth of a few inches, the larvae found were *A. gambiae* 7, *A. coustani* 13, *A. obscurus* 7, *A. squamosus* 18, and *A. moucheti* 5.

At this time of the year, the height of the rainy season, there is scarcely any surface water on the high ground above the swamp edge. There are no shallow pools on the lateritic gravel or the well drained slopes. But the few deep borrow pits may contain water at this time of the year, and can be just as dangerous as they are in Freetown. At Rokupr, with so much swamp land to claim the attention, they are particularly liable to be overlooked. Conditions at the inland swamp of Royel were particularly instructive in this respect. Here, very few larvae, none of them *gambiae*, were found in the whole swamp area, or in the deep water rice plots. But a single large borrow pit in among an isolated group of houses was found swarming with *gambiae* larvae, 70 full grown being collected in a short time, sufficient to explain the 25 adults caught in the same houses.

November.

At this time of the year all the rice in the swamps is well grown, and the smooth ground at the base of the rice either dries up quickly or is washed by the high tides. Away from tidal influence, the rice may be flooded with stagnant weedy water. In the rice fields themselves *gambiae* is not very common at this stage.

From shallow water among mature rice in Piggery swamp the larvae taken were *A. gambiae* 2, *A. constani* 23, and *A. squamosus* 2.

In exposed shallow pools among the high rice were found: *A. gambiae* 23, *A. coustani* 4, and *A. squamosus* 62.

The association of *squamosus* with *gambiae* in rice fields at this stage of cultivation has already been noted at Maswari.

At this time of the year all the ground along the swamp edge, which is too dry for rice, is being made into sweet potato mounds (Pl. V, fig. 6). This includes many of the flat plots used for rice nurseries in the rainy season. The ground between many of these mounds is dry, but in other places there are numerous small pools, now becoming the main breeding place of *gambiae* to judge by the number of full-grown larvae. Breeding was also found in pools in the ditches between banana ridges.

In the inland swamp at Royel the water is still deep and choked with vegetation. Not a single *gambiae* larva was found here, or in the Mesa valley, which is completely covered with well grown rice.

February.

This month is well into the dry season, which extends from mid-November till May. The rice harvest has been gathered, and the rice lands are covered with stubble and mostly dry. The edge of the swamp, where nearly all the breeding occurred from May to December, is now mostly dry, and this includes most of the sweet potato plots above the highest tide mark. In all previous visits every high tide flooded over the river bank, to cover a varying extent of rice land. At this time of the year the river is low, and the high neap tides—*i.e.*, tides lower than about 8 feet—only reach the top of the river bank and no more. As a result the rice flats are only flooded by the high spring tides, and the pools left by these tides remain undisturbed for about a week at a time during the neap tide period. Conditions on the rice flats are now rather like those of the *Avicennia* orchards where *melas* breeds, being flooded at spring tide and drying up during neap tides.

The picture now is quite different from that of the rains. Any pool between the swamp edge and the river bank is now liable to produce *gambiae* larvae, and those large stretches of flat rice land along the river bank which were quite harmless in all previous visits, may now have odd pools swarming with larvae (Pl. V, fig. 4).

Those sweet potato plots which are reached by the highest tides may have numerous pools between the mounds, particularly suitable for *gambiae*. The numerous pools left in freshly ploughed rice plots in the experimental farm area were also breeding places, the breeding being more extensive than at any other time of the year.

Conditions in the flat experimental farm are not representative of the Scarcies in general, and although the breeding places of *gambiae* are now more widely dispersed over the village lands, and along the flat banks of the river, than at any other time of the year, the number of breeding pools is fairly limited as much of the ground dries up too quickly after the tides have receded.

In the Piggery swamp, the outer part affected by the spring tides drains quickly, and most of the ground was quite dry, except for one group of pools near the river bank breeding *gambiae* in numbers. The upper part of the swamp, beyond tidal influence, is almost completely dry, water being restricted to a narrow central stream. The sweet potato and cassava plots are extending further towards the centre of the swamp every day, taking in all the ground that was used for rice in the rains. Most of this ground is dry, and those pools that were present were negative.

Conditions in the inland swamp of Royel are particularly interesting. In all previous visits this whole stretch of swamp land was found to be almost entirely free of *gambiae* breeding. Now, the whole area is drying up, and the narrow central stream fairly well defined. The ground is still boggy with patches of water choked with vegetation, in which few larvae were found. But here and there the surface water had shrunk to form shallow sunlit pools on mud. There were several of these between the land and the central stream, and all contained *gambiae* larvae of all stages. Dense breeding now occurred in a swamp that had been free of *gambiae* for many months. How long this phase lasts is difficult to say, but the deep water rice plots and the sweet potato patches here were all dry, suggesting that with two months of dry weather still to go, these surface pools would probably soon dry up too.

In the narrow inland swamp of Mesa valley, drying has proceeded much further, with the Mesa stream now confined to a well defined bed, and the banks mostly dry. Dense breeding of *gambiae* was restricted to the lower end of the valley, where pools left on flat ground by previous high spring tides produced large numbers of larvae (Pl. V, fig. 4). These pools among the rotting rice stubble were much the same as those on the banks of the river described above. In one of these shallow pools over 100 larvae could be taken in one dip. Like the Royel swamp this valley produced very few breeding places in all previous visits during the rice season, and was of little importance for *gambiae*. The dense breeding of the dry season is much more restricted than at Royel, but it is important because it is just beside Rokupr village.

Larvae collected from all these places round Rokupr in this dry weather visit are shown in Table XVI.

These figures also show how unimportant these grassy-edged streams are from a malaria point of view, the complete absence of *funestus* being unexpected (Pl. VI, fig. 1).

TABLE XVI.

Larvae collected from different kinds of breeding place at Rokupr in the dry weather, February, 1944.

Description of breeding place	Larvae found	
	gambiae	*coustani*
Sweet potato plots	75	—
Pools in rice fields left by tide	358	—
Ploughed fields	56	—
Relict pools in inland swamp	73	—
Small grassy-edged streams in inland swamps ..	4	21

As so many of the breeding places of *gambiae* at this time of the year are produced by the high spring tides twice a month, and dry up during the neap tides, it seems fairly certain that this must cause corresponding peaks of adult production, such as occurred with *melas* at Aberdeen (see page 194). In these pools there were many full-grown larvae and pupae on 16–18.ii.44, *i.e.*, about 3–5 days after the pools were left undisturbed by the falling tides. There is this difference however, *melas* larvae start developing right from the beginning of the spring-tide period, when they are covered by tide water every 12 hours. *Gambiae* larvae have never been found in such conditions at Scarcies, pools flooded by the tide every day being consistently negative. With *gambiae*, breeding apparently starts and progresses only when the shallow pools are left undisturbed, *i.e.*, after and not during the spring tide period.

Although the observations at Rokupr were not continuous enough to enlarge on this, it seems fairly certain from a study of the breeding places, that in the dry weather there is a peak production of *gambiae* adults at the end of each neap tide period in the whole Scarcies area. To what extent this peak would be reflected in house catches, where there is already a high population of *gambiae* adults, could only be determined by more regular observations.

Summary of Scarcies Survey. The investigation, which started with the object of extending observations on *gambiae* breeding in rice fields, eventually embraced all breeding places of *gambiae* in the area. A piece of ground covered by swamp rice at one period of the year may later become a sweet potato garden, or be left fallow as dry ground or as a boggy sedge swamp. It would therefore be pointless to concentrate on one wet crop while ignoring others equally dangerous.

At Rokupr there is such a variety of conditions existing that it is felt that many of the observations made here will have a direct bearing on other parts of the Protectorate, where swamps and wet cultivation exist.

One of the most striking features during and immediately after the rainy season, *i.e.*, roughly six months from June to November, is that with great expanses of water and innumerable pools present, dense breeding of *A. gambiae* is restricted to the extreme swamp edge zone, and to only a small fraction of all that edge. Where breeding does occur, it is usually very dense over a limited area, and one or two of these restricted breeding grounds may be sufficient to account for the high catches of adults in houses. There is no reliable way of forecasting where these breeding grounds will occur; much depends on the stage and type of cultivation, on rainfall and on tides, but once one is found it is likely to be a fairly regular breeding place for at least a month or two. This is borne out by the fundi plot in Piggery swamp, dangerous in June and July, and the deeply ploughed plots and sweet potato mounds in the upper part of the experimental farm.

As the rainy season advances the breeding grounds tend to shift or disappear completely. In general they change with the changing level of the swamp edge, keeping to the fringe of the dry land where pools still depend for their existence on rain showers. Small pools in a thick "grassy" bed, whether it is a rice nursery, a fallow nursery, or a fundi field, are evidently just as suitable as shallow puddles on the exposed mud of ploughed fields or rice plots.

During that six-month period, by far the greater part of the swamp and rice land is quite harmless, as also is the greater part of the swamp edge where conditions may appear very similar to those of the breeding grounds. The two inland swamps were also almost completely free of *gambiae* at this time, and no important breeding grounds were ever found in a great length of swamp edge examined.

Provided that the breeding grounds have been detected, their number and nature is such that they could be controlled fairly easily, with a probable great reduction in the number of *gambiae* mosquitos. But the search must be thorough, as any control scheme which overlooked a new breeding ground would have its efforts largely wasted. The existence of the occasional flooded borrow pit on the high ground, away from the swamp edge, would have to be considered here just as much as in any other part of the country where *gambiae* is found.

In the dry weather, the picture gradually changes, and breeding places are liable to occur over a wide area of rice land hitherto free from *gambiae*. Owing mainly to the tidal nature of the river, abundant pools are produced at regular intervals throughout the dry weather, on the flat rice land which would normally dry up completely for several months. At the same time, inland swamps, harmless in the rains, are also drying up and passing through a phase when pools suitable for *gambiae* breeding are created. The length of this phase will depend on the drainage which may be sufficient naturally to dry the swamp quickly as in Mesa valley, or may be prolonged to provide suitable breeding conditions over several months.

Owing to all these factors, *gambiae* breeding in the Scarcies is more extensive in the dry season than in the rains, which is exactly the opposite of conditions in the rocky colony where Freetown is situated, and where breeding in the dry season is very limited and a definite off-season is produced in most places.

There are no figures to show accurately the relative abundance of *gambiae* adults at Rokupr at different seasons of the year, but at least we can say from hand catches that at no time of the year was there much difficulty in catching large numbers in houses. The actual numbers caught depended on the material required, and give no real indication of the population, but adults seemed to be rather less common at the end of the heavy rains—September visit—than at other times of the year.

In the dry weather breeding places are scattered over a greater area of flat rice land than in the rains, but apart from the experimental farm area where conditions are not typical of the Scarcies, the number of these breeding places is again such as to make their control not a matter of great difficulty. Success again depending on thorough search and an appreciation of the part played by the spring tides.

Although there is no immediate suggestion that anti-malarial work will ever be extended to such parts of the Protectorate, the experience at Rokupr has shown that even in this outstation, notorious for its mosquitos and presenting at first sight an apparently insuperable problem, a great reduction of *Anopheles* could be achieved fairly simply by a thoroughly trained, conscientious African, employed on full time control. The growing importance of this agricultural station, and the presence of trained Europeans interested in the work, suggest that Rokupr would be an ideal place to try out these direct control methods. This would be a real and convincing test, because it is fairly certain that further surveys up-country in the Protectorate would reveal local malaria problems that could be dealt with much more simply than Rokupr.

The Influence of some Physical Factors on the Selection of Breeding Place by *A. gambiae.*

Salinity.—In the account of the distribution of *A. melas* and *A. gambiae*-type eggs (see page 188), it was shown that the great majority of *gambiae* eggs were found in fresh water pools, and that there were only odd records of eggs from brackish water. The work of Ribbands (1944a) has shown that *gambiae* larvae can develop successfully in 37 but not in 50 per cent. sea water. Knowing the degree of salinity necessary to make a breeding place unsuitable for *gambiae* larvae, it now remained to find out what degree of salinity would prevent females from laying eggs in what would otherwise be a suitable place.

A regular breeding ground of typical *gambiae* was found at Aberdeen Creek, just above the highest tide mark. During the rainy season of 1942 *gambiae* was recorded regularly from flooded footprints and wheel ruts, and also from small artificial pits dug in the ground. A series of small shallow pits—about 9 inches in diameter—was dug beside the breeding patch, a few feet beyond the highest tide mark. Egg collections soon showed that *gambiae* was laying regularly in the fresh water of these pits.

The ideal experiment would have been to raise the salinity gradually, and find out the number of eggs laid at each stage of salinification. During the rainy season this was impossible, as heavy rain periodically flooded all the pools. The observations were therefore confined to the short spells of dry weather that occurred in the rainy season ; egg collections were only related to the salinity of the water when there had been no rain on the previous night. Sea water introduced into an ordinary shallow pit was soon washed away by subsoil water movement, and in order to maintain the salinity level constant for a day or two at a time the following device had to be used. A large pit was dug, sufficient to hold a large bucket so that its rim was flush with the surface of the ground. The bucket was filled with soil in which the small experimental pit was excavated, the soil round the small pit now being unaffected by subsoil water in the ground outside. Varying amounts of sea water were added to the fresh water in the small pits where egg-laying occurred regularly, and the gravid females were therefore given a natural choice of brackish water or of fresh water in the control pits.

The results of observations extending over four weeks in September, 1942, are shown in Table XVII.

TABLE XVII.

Influence of salinification of breeding place on egg-laying of *A. gambiae.*

Experimental pool Salinity (per cent. sea water)	Eggs laid	Eggs laid Fresh water control
7	18	—
—	95	—
9	91	—
16	22	—
22	33	37
27	50	68
31	14	19
38	5	48

From these experiments it appears that up to about 30 per cent. sea water, the female *gambiae* selecting a breeding place is indifferent to salinity, ovipositing in such brackish water even when fresh water is available within a few yards. Eggs are still laid in water with a salinity of 38 per cent. sea water, and it is evident that the female is not so sensitive to salt as might be imagined from its breeding habits.

These figures must not be interpreted as meaning that *A. gambiae* will oviposit in all pools with salinity below 38 per cent. sea water. They only mean that in a regular breeding place salinification alone will not render the water unattractive to the egg-laying female until the salinity has reached 38 per cent. sea water. The figure of 38 per cent. sea water as the limit tolerated by the female mosquito is almost identical with that of 37 per cent. recorded for the larvae by Ribbands, and means that *A. gambiae* will not oviposit in water in which the salinity is too high for successful development of the larvae.

Light and Shade.—One of the main features of the typical *gambiae* breeding place, wherever this species is found, is that the water is usually fully exposed to the sunlight ; the more shade there is, the less likelihood of *gambiae* appearing (Leeson, 1937), and this has certainly been borne out by our own observations in Sierra Leone.

But although the knowledge that a certain species "likes" shade, and that another species "does not like" shade, is sufficient for most practical purposes, there are actually very few cases where we can say definitely what this liking amounts to. A recent study on the influence of this factor on *A. minimus* (Thomson 1940) has yielded most unexpected results, and shown that secondary factors, associated with light and shade, may really be the ones with the greatest influence on the behaviour of the mosquito. Furthermore, the reactions of the female mosquito looking for a breeding place may be quite different from those of the larvae living in that water.

Towards the end of the dry weather, in April and May, 1943, ideal conditions for field experiments on *gambiae* were found in a sweet potato patch near the edge of Wellington swamp (Pl. V, fig. 5). Typical *gambiae* were found breeding regularly in small puddles between the potato mounds ; and when a series of small pits, about 9 inches in diameter was constructed, they were immediately invaded by this species. Some pits were modified, while others a few feet away were left untouched as controls. The pits were shallow, bare-edged, and contained clear fresh water of low organic content (seldom equivalent to more than 2·0 gms. O_2 per litre absorbed from acid permanganate, in 4 hours at 40°C.).

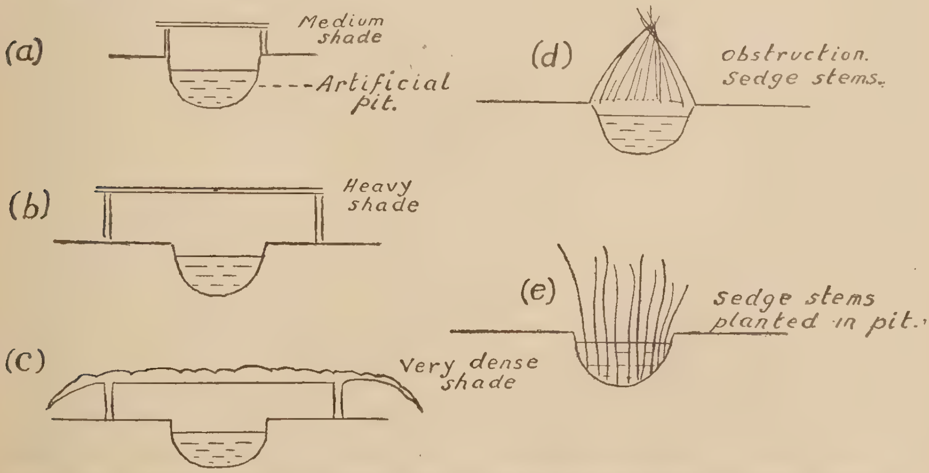


FIG. 8. Diagrams illustrating experiments on influence of physical factors on selection of breeding place by *A. gambiae*.

Three experiments involving three degrees of shade of increasing intensity were used to determine the reactions of the female mosquitos. A framework of bamboo, with thatch or palm leaves superimposed, was erected over a pit which was a regular breeding place, and the number of eggs laid during a period of one or two weeks compared with that from an unshaded control. The thatch shade was constructed to produce as far as possible shade without obstruction, and as each experiment did not last more than two weeks there was less chance of the shade introducing secondary factors. The results of these experiments are shown in Table XVIII and fig. 8.

Table XVIII.

Effect of different degrees of shade on egg-laying of *A. gambiae.*

	Eggs	
	Shade	Control
A. Medium shade (fig. 8A) .. .. .. 1½ × 1½ × 1 foot above ground. 7 collections.	165	158
B. Heavy shade (fig. 8B) .. .. 3 × 3 × 2 feet above ground. 3 collections.	149	83
C. Very dense shade (fig. 8C) .. .. .. Same as B with thatch extended. 5 collections.	96	94

The final degree of shade unavoidably introduced greater obstruction to the flight of the mosquito, but this evidently was of little importance. From these figures it is obvious that this degree of shade is not repellent to the female mosquito, and that tohər things being equal, the female will lay indiscriminately in exposed and in heavily shaded water when it is offered a choice. The important clause in that statement is "other things being equal", because that seldom is the case in nature. The idea of a surface pool differing from the typical breeding place in only one factor, shade, must be extremely rare. Under natural conditions shade is usually associated with obstruction offered by dense vegetation, or with decaying organic matter originating in the plants or trees which produce the shade. From the above observations therefore one is only justified in concluding that in a regular breeding place of *gambiae* the introduction of shade alone is not sufficient to make the water unattractive to the egg-laying female.

The effect of shading the breeding place on the subsequent development of larvae has not been fully investigated, as experiments were interrupted by heavy rain, but the following observation is interesting. On 21.v. a small shallow pit or earth well in this potato plot yielded 53 *gambiae* larvae and 7 pupae. A framework of heavy shade was erected over the pool. Twenty days afterwards, the water in the pool had sunk very low, but many *gambiae* larvae were found, mostly in the young and intermediate stages, but eight full-grown larvae were included. The shade was still very dense, and we had to crawl under the thatch to reach the water. The shaded water must have been considerably cooler than the sunlit breeding places, introducing another factor ; nevertheless larvae could still develop, although how many and how quickly is not known. The observations, incomplete though they are, suggest that shading a breeding place does not render it completely unsuitable for development of larvae.

Iron Bacteria.—Most of the small pits used in the experiments described above very soon developed an iridescent film or scum due to the activities of iron bacteria. On removal to the laboratory this film disintegrates and forms a reddish precipitate that soon settles on the bottom of the dish. Attempts to produce a film in the laboratory from mud-lined dishes were not very successful, though films broken up in the field reform overnight. Observations in Assam (Thomson 1942) have shown that in that part of the world the characteristic film is associated with undisturbed water almost devoid of dissolved oxygen, and not necessarily with water of high organic content. In Sierra Leone the film is unaffected by salinity, being common in tidal areas and undisturbed salty pools.

Despite the complete surface film in these experimental pits, eggs were laid regularly. In one pit in swamp soil just above high tide mark the scum was particularly firm and persistent, and in 18 collections yielded eggs of *A. gambiae*-type 507, and *A. melas* 107. The *gambiae*-type eggs were taken on every occasion, the *melas* eggs on 11 only.

Although eggs of both species were laid regularly, no larvae were found over a period of three weeks while the film persisted. When the film was broken up by a shower of rain, large numbers of young larvae appeared, only to disappear on the following day when the scum reformed. With more regular showers, larvae were able to grow sufficiently large to break up the film, and large numbers of them finally pupated.

These observations show rather strikingly how the female may persist in laying eggs in water which at the time is quite unsuitable for the larvae. This iron film is seen in many surface pools, particularly in the dry weather, or where there is a great deal of decaying vegetation. As the above observations show, it is by no means an infallible guide to absence or presence of breeding. A complete film indicates that there are no growing larvae present, although dormant eggs may be there only needing a break in the film to hatch and develop. Although the water may constantly tend to produce a film, the presence of growing larvae older than the first stage tends to break up the film more and more till finally it disappears.

Mechanical Obstruction.—Mechanical obstruction as a factor influencing the behaviour of the mosquito has recently been demonstrated by Russell & Ramanatha Rao (1940) in *A. culicifacies*, in South India. They were able to show that the gradual disappearance of this species from rice fields with the growth of the rice plants is due to the mechanical obstruction caused by increased density of the rice stems interfering with the flight of the female when it is looking for a place to lay its eggs.

The influence of this factor on female *gambiae* was investigated in the same pits described in experiments above. Sedge stems were planted round the rim of small pits in which eggs had been laid regularly, and the number of eggs laid over a period of one or two weeks was compared with the numbers from an untouched control. The diameter of the pit at ground level was about eight inches, and the sedge stems were planted well above water level (fig. 8, *d*), sloping slightly inwards so that their tops interlaced with each other about a foot above the pit. In the first experiment 50 stems were planted round the 25-inch rim, giving a maximum space of ½ inch between the bases of the stems. In the second experiment 100 stems were used, giving less than ¼ inch as the greatest space between the stems. To counteract any bias, the pit obstructed in the first experiment was cleared and used as control in the second experiment.

The results are shown in Table XIX.

TABLE XIX.

Effect of mechanical obstruction on egg-laying of *A. gambiae*.

		Eggs laid	
		Pit with stems	Control
Expt. 1	Pit obstructed with 50 sedge stems .. 6 collections.	51	203
Expt. 2	Pit obstructed with 100 sedge stems .. 6 collections.	26	136

Throughout the 12 collections which made up the figures, the number of eggs laid in the obstructed pit was consistently lower than that of the control pit, suggesting that mechanical obstruction of this kind is a factor of some importance in deterring the female mosquito from laying eggs. It certainly appears to be a factor of more importance than shade in this respect, and it is possible that some of the effects commonly attributed to shade may really be due to obstruction, particularly when the shade is caused by a dense tangle of grass at the edge of a swamp or stream.

A different type of mechanical obstruction is offered by planting sedge stems in the pool itself, after the manner of rice in a rice field. In two series of experiments, 50 and 100 sedge stems were planted in the experimental pool (fig. 8, *e*) and the number of eggs laid compared with that of an untreated control. In seven collections the pit with sedge stems produced 192 *gambiae* eggs, compared with 227 in the control. Within this limit this type of obstruction had no deterrent effect, and the pits also continued to support many larvae. Experiments involving even denser bunches of sedge stems were interrupted by heavy rain.

The ineffectiveness of this type of obstruction was borne out by later observations on *A. gambiae* in rice fields. Not only was *gambiae* found breeding in among rice at all stages of cultivation, but it was also found abundantly in pools where there was a thick vertical growth of grass stems, such as a rice nursery (Pl. IV, fig. 4) and in a field of fundi.

Anopheles nili, a Vector of local Importance in Sierra Leone.

In most parts of Africa, including Sierra Leone, where *A. nili* has been encountered, only small numbers have been found inside houses (Evans, 1938). But in some localities in the Belgian Congo (Schwetz *et al.*, 1929) and in Liberia (Barber *et al.*, 1932), it has been recorded as fairly common in native houses. In such places it becomes important in malaria transmission, the infection rates being as follows :—

		Per cent. infection	
Authority	*Country*	*Oocyst*	*Sporozoite*
Schwetz *et al.*	Belgian Congo ..	10·0	5·3
Barber *et al.*	Liberia	14·6	0·8
Gordon *et al.*	Sierra Leone (Kissy) ..	18·2	9·1

In Kissy, the numbers found by Gordon *et al.* (1932) were very small, 28 adults being found in 582 rooms, all in May and June, and it was not considered of much importance in that district.

In the present investigation, *A. nili* was first found to be of local importance in the Orugu Valley which runs just behind the range of hills which forms the background of Freetown. This area was included in a survey of rivers and streams to find the dry weather breeding places of *gambiae*. As we have already described (p. 227) there is very little breeding of *gambiae* in the entire length of the Orugu river, and in the houses, the dominant Anopheline in the dry weather was found to be *nili*.

House catches were made in Regent village at the head of the valley, in Charlotte village half way down the valley, in Bumpeyo (Pl. VII, fig. 4), a little group of houses beside the military camp where the Orugu valley starts to widen out to form the Grafton valley, and at Upper Allen Town, the village nearest the last stretch of the Orugu. *A. nili* has not been found in Regent, and only a few specimens have been found in Upper Allen Town. The highest catches came from Charlotte and Bumpeyo, and are recorded in Table XX.

TABLE XX.

Anopheles adults caught in Orugu Valley (Charlotte and Bumpeyo villages), January to June, 1943, and March, 1944.

Month	Total	*A. nili*	*A. gambiae*	*A. funestus*	Percentage of *nili* in catch
January .. .. .. February .. .. March	233	212	19	2	91
June	102	48	48	6	47

From this table it is seen that *A. nili* forms over 90 per cent. of Anophelines caught in houses in January to March, while by June *nili* and *gambiae* are about equally abundant. *Funestus* evidently plays a very minor part. The total *Anopheles* caught in these houses is much greater than the table suggests, as many catches were sent direct to the Malaria Field Laboratory for dissection. This, together with the fact that the visits were irregular and infrequent, makes it difficult to follow the variations in the numbers of *nili* during the six months from January to June. But as a rough idea of the density of adults, 87 *nili* were caught on one occasion by a single collector in a group of houses in Charlotte, collecting for a period of 1½ to 2 hours. In every catch nearly all the adults were blood fed.

The samples sent to the Malaria Field Laboratory were dissected, and figures showing the results—supplied through the courtesy of Lt.-Col. Tredre—are shown in Table XXI.

TABLE XXI.

Infection rates among *A. nili* caught in Orugu Valley, January to June, 1943.

No. dissected	No. of stomachs examined	No. positive	Per cent. positive	Glands examined	Glands positive	Per cent. positive
106	104	6	5·8	93	3	3·2

Breeding Places. No breeding places of *nili* were found in the upper part of the Orugu, above Charlotte Falls, but below this point they were found at several points between Charlotte and Bumpeyo. In the lower part of the river, near the main Freetown-Hastings road, only a few larvae have been found. The larvae collected from the whole Orugu river are listed in Table XIV (see page 227).

These figures agree well with adult catches, and show that the amount of *gambiae* and *funestus* breeding in the stream is insignificant compared with that of *nili*. Most of the *nili* breeding occurs in the level stretch of the stream between Charlotte and Bumpeyo (Pl. VIII, figs. 1–3). The distribution of the larvae is shown in Table XXII.

TABLE XXII.

Distribution of *A. nili* larvae in different breeding places in the Orugu River.

Shaded or partly shaded backwaters, with steep bank and fringe of grass or grass roots (Pl. VIII, fig. 2)	103
Clumps of grass and weed round boulders in mid stream (Pl. VIII, figs. 1 and 3)	40
Pools at edge of stream	12

From this it is seen that most of the *nili* larvae were found in two rather different types of breeding place, the partly shaded backwater (Pl. VIII, fig. 2) and the exposed clumps of weed tangled round boulders in mid stream (Pl. VIII, figs. 1 and 3). The breeding places were not limited to those parts of the river beside the villages, but were also found in the stretch of river between the two villages, where there are no houses anywhere near. Not a single *nili* larva was recorded from the numerous pot holes and depressions on the rocks in which so many larvae of *rhodesiensis* were found. The *freetownensis* larvae were all taken in shaded pools with dead leaves along the edge of the Orugu at Charlotte.

Larvae of *nili* have also been found in Wellington Brook, 6 larvae in 2 collections in April, and in the shaded stream at the east end of Wellington village, 50 larvae in one collection in April, but their appearance in these streams is sporadic, and *nili* adults have not been found in Wellington village.

From these observations in the Orugu River there is little doubt that *nili* is an important vector of malaria for at least 6 months of the year, and that in the dry months it is the principal vector from Charlotte to Bumpeyo. Apart from these two villages, the steep-sided Orugu valley (Pl. VII, fig. 3) is very sparsely populated, but the lower limit of *nili* abundance marks the beginning of a long series of Army camps and establishments stretching down the Grafton Valley towards Hastings. In fact Bumpeyo village is right inside the Grafton Valley camp, and must act as an almost constant source of infection to the European and African personnel living round the village, particularly when it is borne in mind that the breeding places of *nili* were quite untouched by the routine measures directed against *gambiae* larvae.

Summary.

Anopheles melas.

The eggs of *A. gambiae* var. *melas* are distinctly different from those of typical *gambiae*, and it is now regarded as a distinct species, *A. melas*. Other workers have found that the larvae also differ, physiologically and structurally. All adults with an extra dark band on the palps —4-banded forms— are known to be *melas*, but those adults with normal 3-banded palps can so far only be distinguished from typical *gambiae* by egg characters.

A. melas is now known to be an important vector of malaria in coastal districts in West Africa. In some estuarine and mangrove swamp areas it may be even more important than typical *gambiae*. In *melas* caught in Freetown estuary (mostly from Wellington village), 42 out of 1,000 glands dissected were positive, giving a sporozoite rate of 4·2 per cent. for all months of the year. The oocyst rate was 4·7 per cent., and the total infection rate was 7·8 per cent.

In Freetown estuary *melas* is rare in Freetown itself, and in the adjoining village of Kissy, but in all other parts of the estuary is at least as important as typical *gambiae*. In many places it is the dominant vector. In Wellington to the east of Kissy, and on the Bullom shore which forms the north shore of the estuary, *melas* forms about 90 per cent. of Anophelines caught in houses.

Dense breeding of *melas* is confined to brackish water and areas flooded by the high spring tides. The amount of breeding that takes place in fresh water, outside the tidal zone, is negligible.

This tidal zone, between low tide mark and high spring tide mark, is characterised by great stretches of mangroves of which there are two main types in West Africa. By far the most common is *Rhizophora*, which has aerial stilt roots and viviparous seeds. It may occur in all parts of the tidal zone and varies in size from small stunted bushes on sandy soil to large trees with the main stem raised 10–20 feet above the mud by the stilt roots. The largest trees are found in the outer mangrove fringe and lining the numerous creeks. Most of the *Rhizophora* zone is flooded every day by the mean high tides.

The other mangrove is *Avicennia*, which has no stilt roots, but the ground round it is covered with a stubble of asparagus-like stalks growing up from the shallow root system. The trees are well spaced, of more uniform size and with rounded crowns. They usually grow on very flat tidal areas which are only flooded by the high spring tides.

It is necessary to distinguish between these two mangroves because dense breeding of *melas* is mostly confined to large stretches of pure *Avicennia*, while *Rhizophora* on the other hand is almost entirely harmless.

Isolated *Avicennia* trees, or even a narrow fringe along the upper edge of the mangrove zone, are not important. It is only when the *Avicennia* occurs in characteristic pure stands, or " orchards ", which may vary in size from 2–3 acres to 50 acres or more, that dense breeding is likely to occur.

The *Avicennia* orchards are important not so much because of the mangrove trees themselves, but because of the flat, badly-drained, peaty soil on which they grow. During the wettest months the flat orchard is frequently flooded by rain water, but in the dry weather it is only flooded by the high spring tides which cover it every 12 hours for 4 or 5 days in each fortnight (or in each month at certain times of the year).

When the *Avicennia* trees are removed, breeding still continues in the open spaces, and among the salt marsh plants which soon appear.

Round the *Avicennia* orchard, breeding may extend a few yards into the *Rhizophora*, and may also occur on the flat grassy shore outside the mangrove zone ; otherwise such places are usually harmless.

In the Freetown estuary the *Avicennia* orchards form only a small proportion of the great mangrove belt, and control is aimed at by building a 3–4 foot bund round the orchard to keep out the spring tides, at the same time draining the reclaimed area and allowing the rain and seepage water to drain away at low tide through a tidal gate or hand-operated sluice. In the Freetown estuary there are five main orchards to be reclaimed in this way.

From high ground or from the air these orchards can usually be distinguished in the dry weather by the very light green colour of the foliage, compared with the slightly darker green of the medium sized *Rhizophora*, and the very dark green of the high *Rhizophora*. They also show up clearly in good vertical aerial photographs, and this method is now being used more and more to locate and map possible breeding grounds in the mangroves.

Breeding of *melas* in these orchards is greatly influenced by the tides, and once a suitable looking place has been found, the best time to visit it is towards the end of the high spring-tide period, either early in the morning before the high tide has flooded the area, or 5–6 hours after high tide. When the falling spring tides no longer flood the *Avicennia*, full-grown larvae are particularly abundant in the pools left behind, although the same pools may produce nothing when visited a few days later. Except in the wettest months of the year the *Avicennia* orchards dry up during the neap tides, and at certain periods in the dry weather the orchard may be quite dry for over three weeks at a time. Unless the time is carefully chosen therefore, it is possible to draw blank even in the most important orchards.

Anopheles gambiae.

The breeding places of *A. gambiae* have been studied in the Freetown estuary area, and in the Sierra Leone Protectorate.

The rainy season extends from about the end of May till the end of October. July, August and September are the months of heavy rainfall, averaging over 30 inches each month. The dry season extends from about mid-November to mid-May, with December, January, February and March with very scanty rainfall.

In the Freetown Kissy region, the most striking feature of the breeding places in the months of heavy rainfall is the number of suitable looking sunlit pools that are negative for *gambiae*. The odd pool or puddle which does breed *gambiae* usually has large numbers of larvae present, and may go on producing *gambiae* for weeks on end.

In old pits and small holes in bare laterite only a small proportion, about 1 in 50 at Kissy, produce *gambiae*. But in recently dug, rain-filled, holes in laterite, dense breeding of *gambiae* may occur in the rainy season. Among the most dangerous type of breeding place in the rains are shallow, rain-filled pools, or groups of pools, flooded footprints or wheel ruts, on soil on level ground ; these places are dependent on rainfall, and tend to dry up quickly after one or two days without rain. In the damp mud left at the bottom of the pool when it dries up, eggs can survive for at least six days, young larvae for two days, and full-grown larvae for several hours ; pupae also can emerge from damp mud.

Among so many negative pools it needs careful search to find the odd pool or puddle that produces all the larvae, and this careful inspection must form the basis of *gambiae* control.

This restriction of dense breeding to the odd pool or group of pools is a striking feature of *gambiae* breeding in every place investigated in the rains, both in the Colony and in the Protectorate.

In the dry weather, conditions inside Freetown are different from those in the rest of the Colony outside Freetown. Inside Freetown the lower more level stretches of the two main perennial streams, the Nicol and Alligator brooks, have foul polluted water, and may produce dense breeding at several points if left unchecked. They are important dry weather breeding places, and must be controlled by routine anti-larval measures. In the general scheme of malaria control in Freetown they are much less important than the breeding places in the rainy season.

Outside Freetown most perennial streams are of very minor importance as breeding places of *gambiae*. In the few that do produce *gambiae* dense breeding is restricted to comparatively few small pools, and is never diffused along the whole length of the stream edge. Outside Freetown sweet potato plots are much more important than perennial streams as dry weather breeding places. In the Protectorate grassy-edged streams are of negligible importance as *gambiae* breeding places.

Studies on *gambiae* breeding in rice fields show that in rice plots reclaimed from tidal swamps by bunding, breeding of *gambiae* is liable to occur right through the rice growing season, at all stages of cultivation. In the great swamp rice lands of the Scarcies, dense breeding in the rains is restricted to the swamp edge zone, and to only a very limited part of that. Within these small breeding grounds *gambiae* larvae may be found in every puddle. By far the greater part of the swampy ground is negative for *gambiae.*

The breeding grounds may occur in rice fields, rice nurseries, sweet potato plots or fallow grassy plots at swamp edge, and are related more to the type of ground than to the type of crop or stage of cultivation.

In the dry weather breeding places are more extensive, in pools left on the rice flats by the tidal river, and in relict pools formed by drying up of inland swamps which were negative for *gambiae* in the rains.

Experiments on the factors influencing selection of the breeding place by the female *gambiae* show that dense shade alone will not prevest *gambiae* laying eggs in a regular breeding place. *Gambiae* will also continue to lay eggs in water covered by a film or scum formed by iron bacteria, although the eggs do not hatch or the young larvae develop till the film is broken up by showers of rain. Mechanical obstruction is a more important factor than shade in deterring the female from egg laying. Salinifying a regular breeding place will not deter the female from laying eggs till the salinity reaches 38 per cent. sea water ; up to 30 per cent. sea water the female is indifferent to salinity.

Anopheles nili.

A. nili has been found to be a vector of malaria in the Orugu valley of the Sierra Leone Colony for at least six months of the year. In the driest months of the year it is about ten times more abundant than *gambiae* in houses in this valley.

The breeding places in the Orugu River, where this species is abundant, are described.

References.

Barber, M. A. & Olinger, M. T. (1931). Ann. trop. Med. Parasit., **25,** pp. 461–508.

——, Rice, J. B. & Brown, J. Y. (1932). Amer. J. Hyg., **15,** pp. 601–633.

Blacklock, D. B. (1921). Ann. trop. Med. Parasit., **15,** pp. 463–471.

—— & Evans, A. M. (1926). Ann. trop. Med. Parasit., **20,** pp. 59–84.

—— & Wilson, C. (1941). Ann. trop. Med. Parasit., **35,** pp. 37–42.

—— & ——. (1942a). Ann. trop. Med. Parasit., **36,** pp. 187–191.

—— & ——. (1942b). Ann. trop. Med. Parasit., **36,** pp. 182–186.

Davey, T. H. (1938). Rep. med. Serv. Sierra Leone. Appendix D.

——. (1940). Key to the Anophelines of Sierra Leone. Freetown.

Evans, A. M. (1931). Ann. trop. Med. Parasit., **25,** pp. 443–453.

——. (1938). Mosquitoes of the Ethiopian Region, II. Anophelini. London, British Museum (Natural History).

Glanville, R. R. (1930). Agricultural survey of the existing and potential rice lands in the swamp areas of the Little Scarcies, Great Scarcies, Port Loko, and Rokel Rivers. Sierra Leone, Govt. Printer. 39 pp.

Gordon, R. M., Hicks, E. P., Davey, T. H. & Watson, M. (1932). Ann. trop. Med. Parasit., **26,** pp. 273–345.

Leeson, H. S. (1937). Bull. ent. Res., **28,** pp. 587–603.

——. (1939). Bull. ent. Res., **30,** pp. 129–161.

Mackay, R. (1938). Second (Final) Report of the Malaria Unit, Dar-es-Salaam, for the period November, 1934, to December, 1936. Dar-es-Salaam, Govt. Printer.

Macluskie, H. (1943). Farm & Forest, **4,** pp. 155–160.

RIBBANDS, C. R. (1944a). Ann. trop. Med. Parasit., **38,** pp. 85–99.

——. (1944b). Bull. ent. Res., **35,** pp. 271–295.

ROSS, R. (1902). Mosquito brigades and how to organize them. London, G. Philip & Son.

——, R., ANNETT, H. E. & AUSTEN, E. E. (1902). Report of the Malaria Expedition to West Africa.—Mem. L'pool Sch. trop. Med., **2.**

RUSSELL, P. F. & RAMACHANDRA RAO, T. (1942). Bull. ent. Res., **32,** pp. 341–361.

—— & RAMANATHA RAO, H. (1940). J. Malar. Inst. India, **3,** pp. 427–446.

SCHWETZ, J., COLLART, A., & GEERINCK. (1929). Trans. R. Soc. trop. Med. Hyg., **22,** pp. 457–463.

SOPER, F. & WILSON, D. B. (1943). *Anopheles gambiae* in Brazil, 1930 to 1940. New York, Rockefeller Foundation.

THOMSON, R. C. M. (1940). J. Malar. Inst. India, **3,** pp. 265–348.

——. (1942). J. Malar. Inst. India, **4,** pp. 595–610.

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1. *Rhizophora* mangrove at edge of Great Scarcies River.

2. High *Rhizophora* forming outer fringe of mangrove belt. Makanshan Creek at high tide.

3. High *Rhizophora* forming outer fringe of mangrove belt, Jui.

4. Sedge and grass swamp forming open shore between upper fringe of *Rhizophora* in the background and high spring tide mark in the foreground. Wellington, west end.

5. *Rhizophora*. The tangle of prop roots exposed at falling tide.

6. *Rhizophora* at high tide.

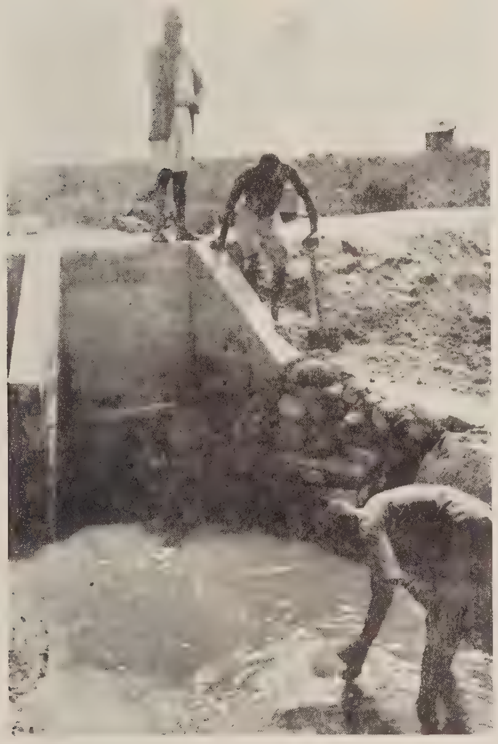
1. A flat boggy area of *Paspalum* outside the mangroves at Lumley end of Aberdeen Creek. Limited breeding place of *melas*.

2 & 3. Wellington. *Avicennia* orchard at low tide showing thick stubble of pneumatophores covering the ground.

4. *Avicennia* orchard at high spring tide.

5. The upper boundary of the *Avicennia* orchard showing the sharp transition from mangrove, on the right, and dry land bush, on the left. Wellington.

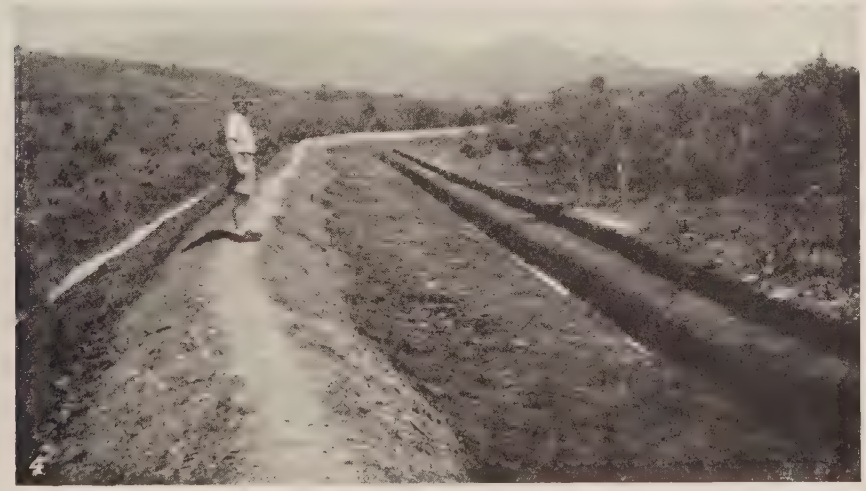
6. Makanshan. Showing the broad open shore of *Paspalum* between the upper fringe of the *Avicennia* on the left, and the high spring tide mark and dry land bush on the right.



1. Control of *melas*. The automatic sluice gate incorporated in the bund at Aberdeen. Outer side with gate propped open.

2. Aberdeen, *Avicennia* area. Open shore of *Paspalum* between upper edge of *Avicennia* on left, and high spring tide mark beyond the right of photograph.

3. Control of *melas*. The first section of the bund at Wellington protecting the orchard on the right.



4. Control of *melas*. The bund cutting through Aberdeen *Avicennia* area, with internal drain on right.

1. Control of *melas*. Mechanical excavators working on bund construction at Wellington.

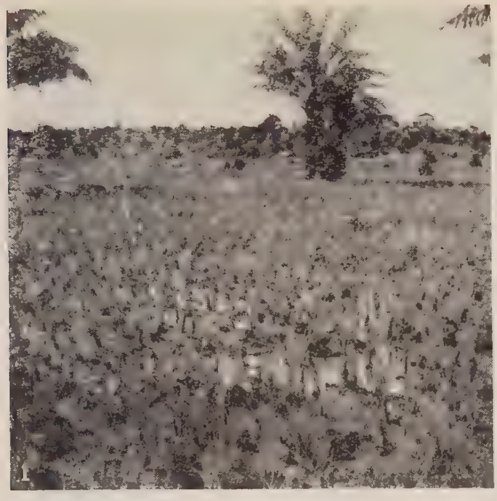
2. Village rice land in Scarcies area, freshly hoed. Dense breeding of *A.gambiae* in pools.

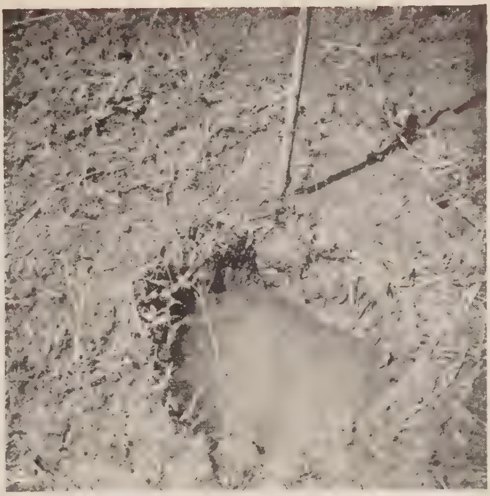
3. Rice nurseries in Scarcies area. Breeding place of *A.gambiae* in rainy season.

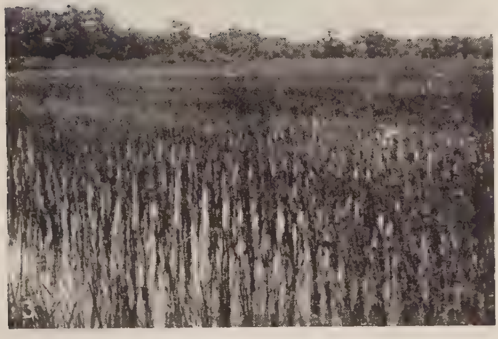
4. Small pools in rice nursery breeding *A.gambiae*.

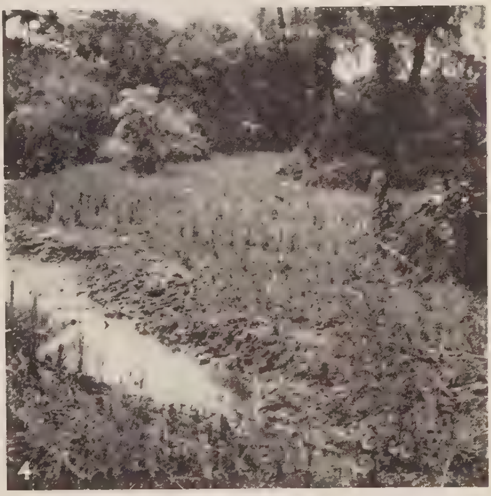
5. Deeply ploughed plots in experimental farm, Rokupr, containing numerous pools left by the river flooding banks at high spring tide. Extensive breeding of *A.gambiae* in dry weather.

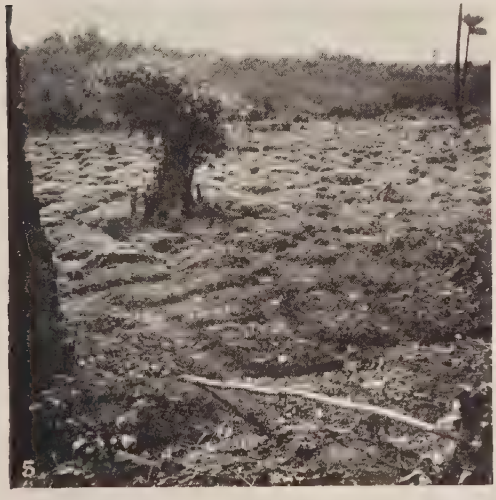
6. Maswari. Large rice plot recently reclaimed from *Avicennia* and *Paspalum* swamp by empoldering. *A.gambiae* breeding in rainy season.

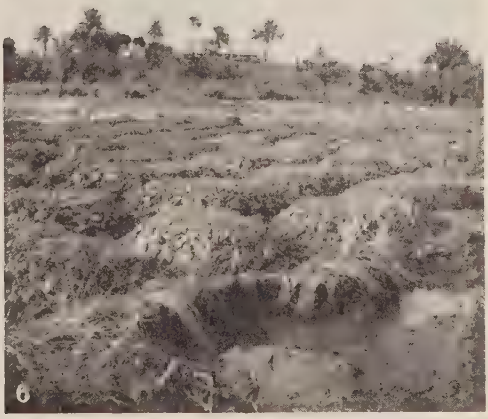












1. Upper edge of swamp rice land at Rokupr. Dense breeding of *A.gambiae* in shallow rain-filled pools among recently transplanted seedlings.

2. Small hole dug at swamp edge in which roots of seedlings are washed before transplanting. Dense breeding of *A.gambiae*.

3. Maswari. An empoldered rice plot reclaimed from tidal area 5 years previously. Rice well grown and plot completely flooded. *A.gambiae* present in small numbers.

4. Pools left in rice land after harvesting in Scarcies area and produced by river flooding at high spring tides. Very dense breeding of *A.gambiae* in dry season.

5. Sweet potato garden just above mangrove and tidal zone at Wellington, west end. A dry weather breeding place of *A.gambiae* and to a very limited extent of *melas*.

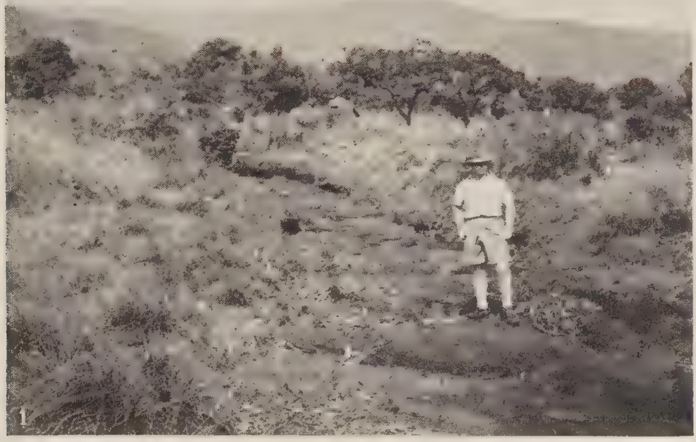
6. Sweet potato gardens along upper fringe of swamp land at Rokupr, Scarcies area. All mounds levelled in the rainy season for rice cultivation. *A.gambiae* breeding localised.

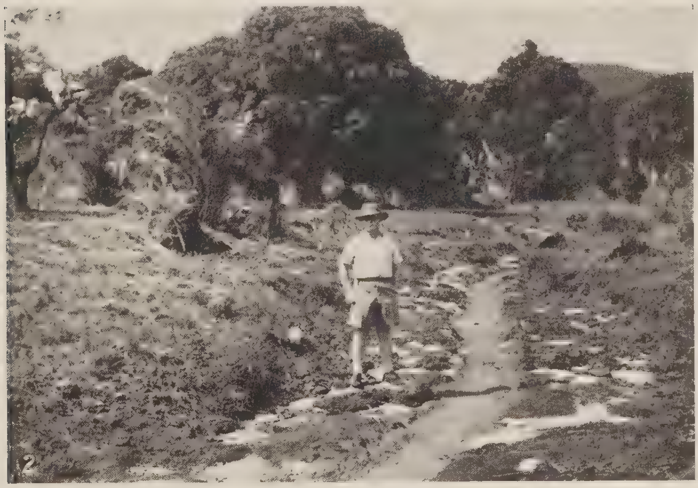
1. Well defined stream left in centre of swamp in dry weather. Mesa valley, Rokupr. Stream not important as a breeding place either of *A.gambiae* or *A.funestus*.

2. Lower part of Alligator river flowing into Kroo bay at Freetown. A notorious dry weather breeding place of *A.gambiae* before temporary canalisation shown in photograph.

3. The Wellington Brook at Kissy. Limited breeding of *A.gambiae* in the dry weather.

4. Lower stretch of the Congo River above Brookfields Bridge. Breeding of *A.gambiae* in dry weather very localised.



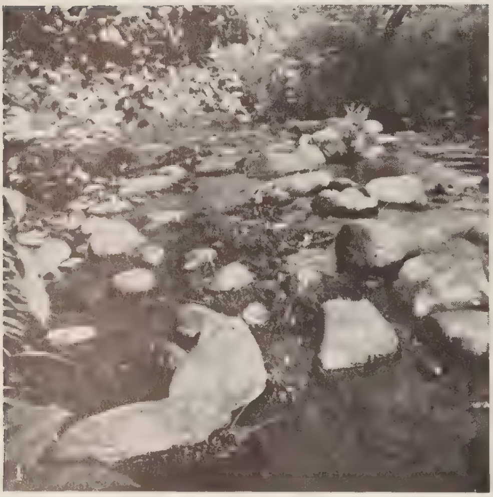


1. The Rekupa Stream near Wellington, showing laterite bed hollowed out into numerous holes and pockets in which dense breeding of *A.gambiae* occurred in dry weather. This was the stream in which flushing experiments were carried out.

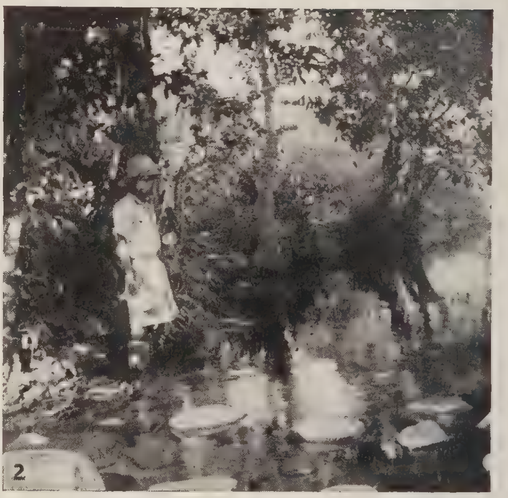
2. Stream bed after treatment. Side pockets filled by concrete and central part of bed canalised to accelerate natural drying of stream.

3. The Orugu Valley between Charlotte and Bumpeyo.

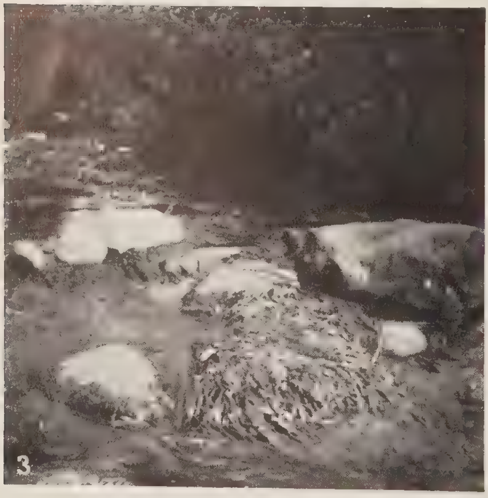
4. Bumpeyo village where large catches of *A.nil* were made in houses.



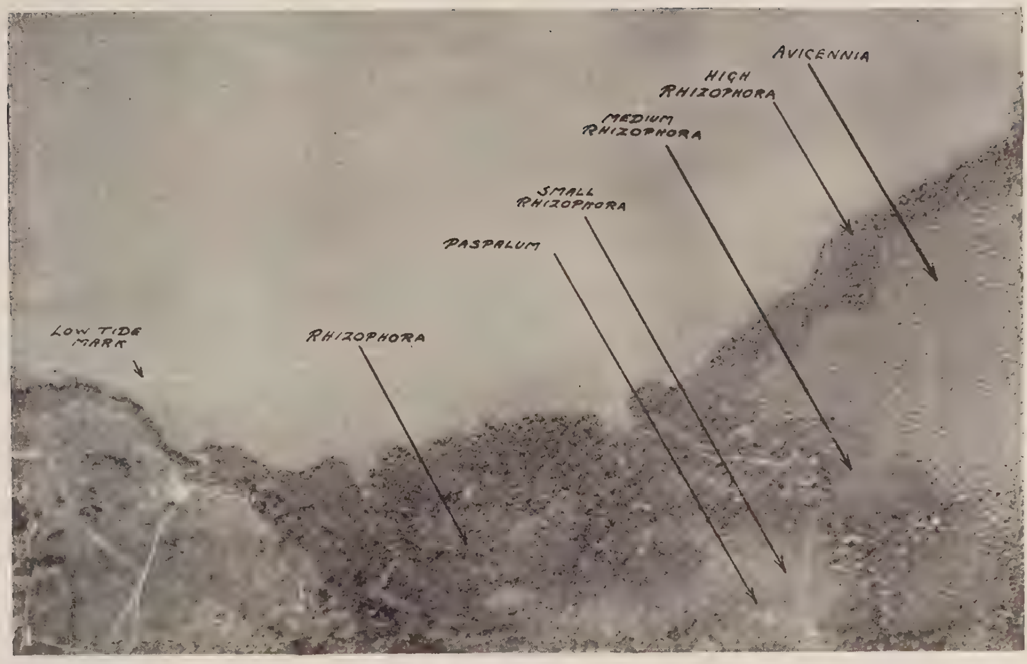
1. The Orugu River at Bumpeyo in the dry weather.



2. Breeding place of *A.nili* in shaded bank of river.



3. Breeding place of *A.nili* among tangled vegetation round boulders in mid-stream.

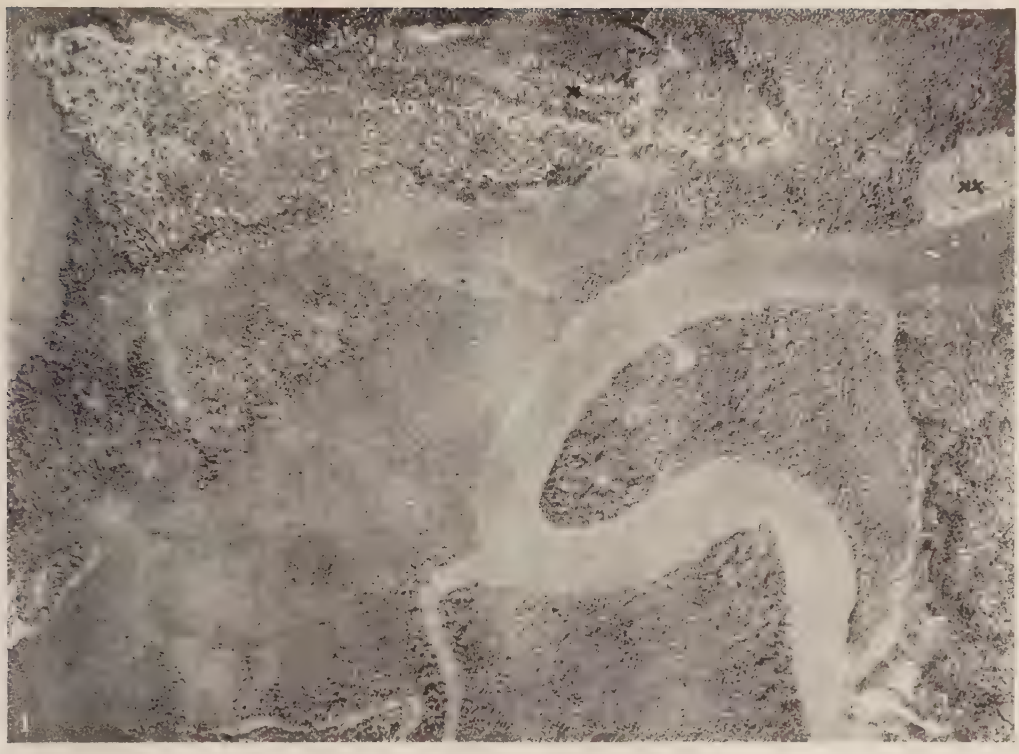

AVICENNIA
HIGH RHIZOPHORA
MEDIUM RHIZOPHORA
SMALL RHIZOPHORA
PASPALUM
LOW TIDE MARK
RHIZOPHORA
1

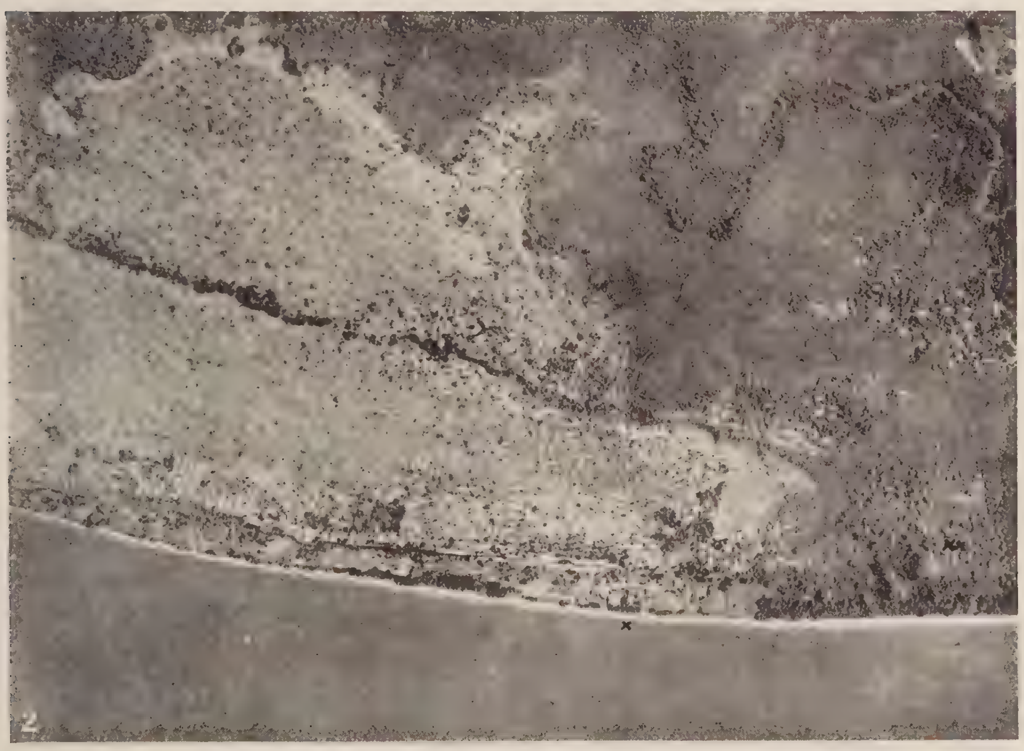
1. Aerial photograph of west end of Wellington mangrove belt showing part of the *Avicennia* orchard.

2. Aerial photograph of Wellington *Avicennia* orchard now being reclaimed (on left) and Coldbath island-orchard (on right).

1. The mangrove belt east of Wellington showing Coldbath island-orchard (on left), Old Wharf orchard (centre), and Kola Tree island-orchard (on right).

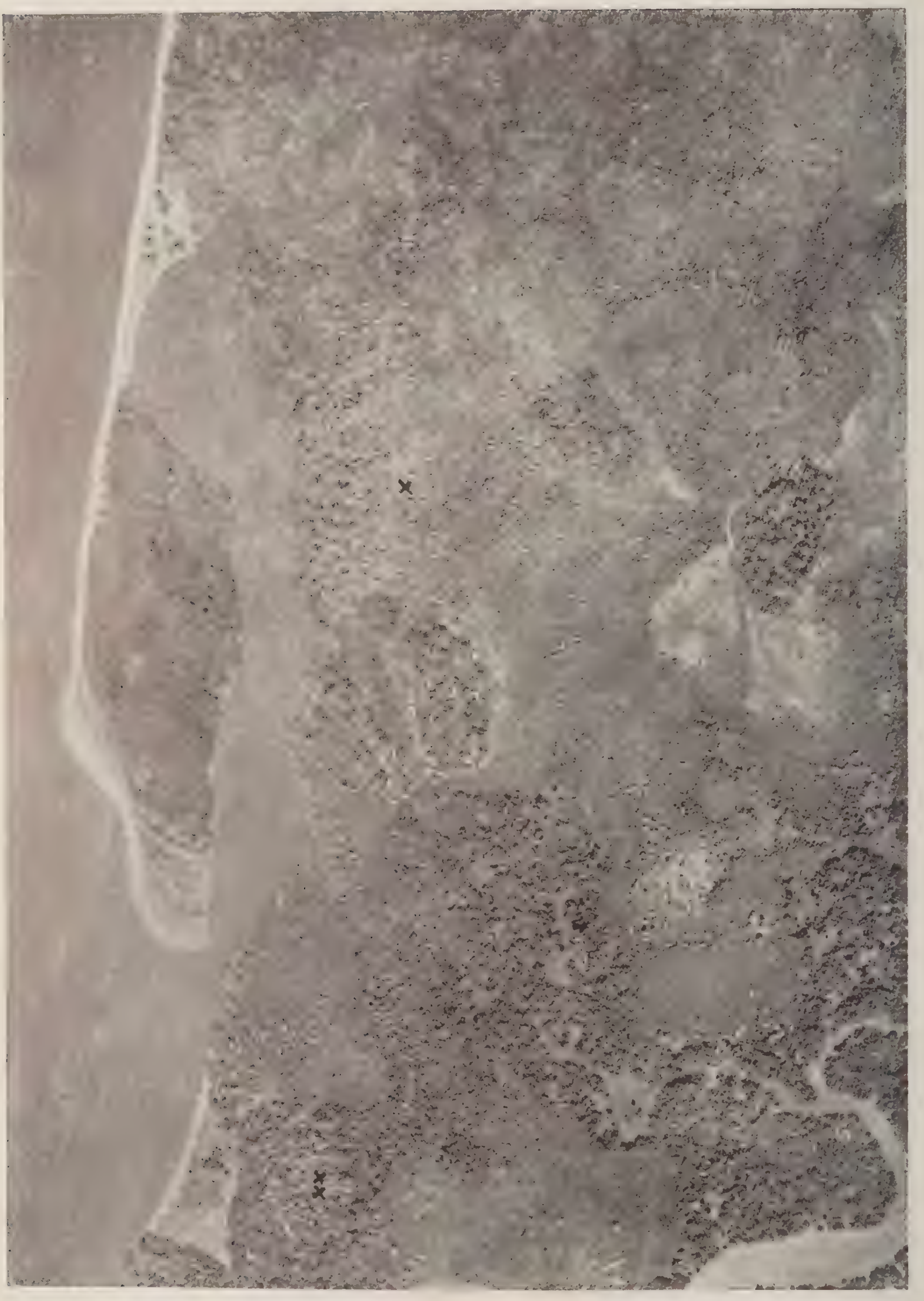
2. Aerial photograph showing Allen Town island-orchard at edge of creek.



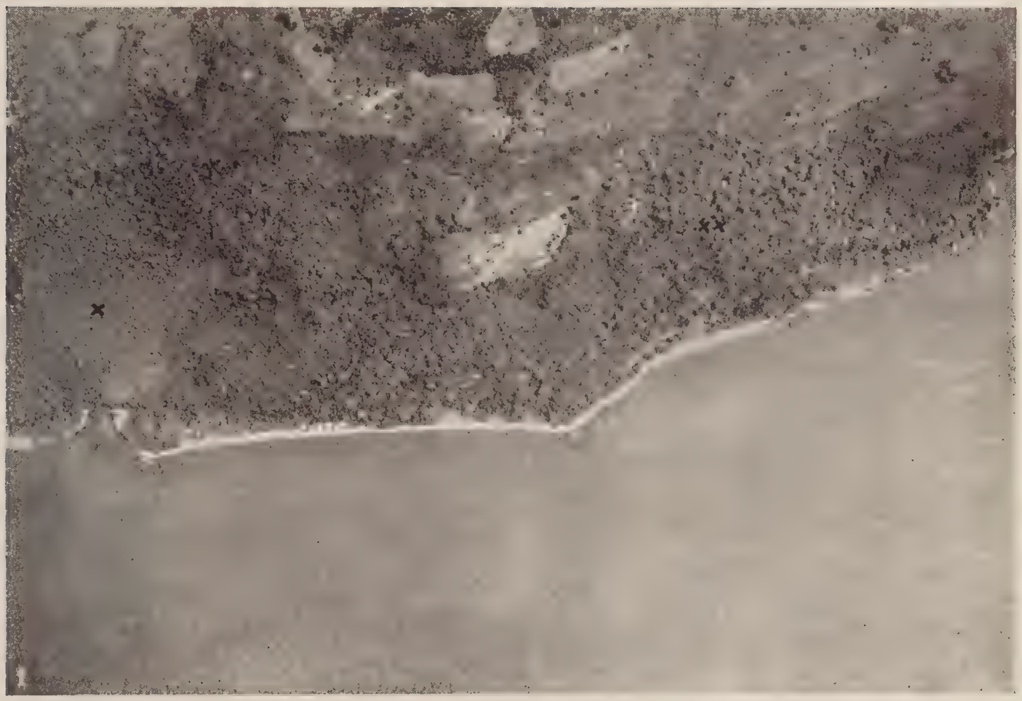


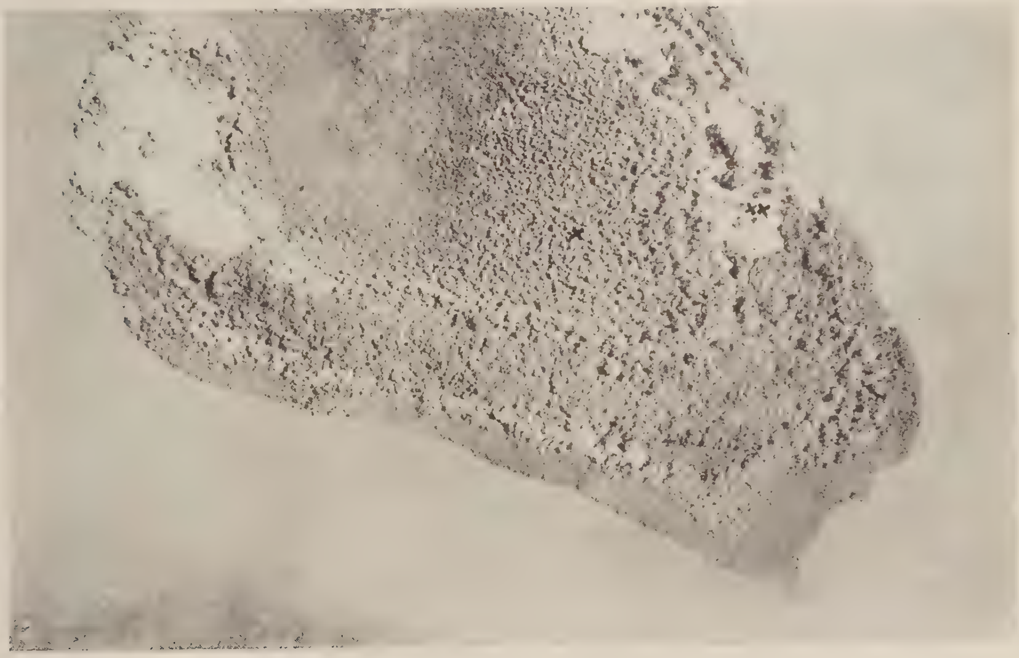
1. Kambia Island near Jui showing *Avicennia* orchard on south of island, negative for *melas*, and small breeding patch on north of island (x). The pale area (xx) shows where mangroves have been felled.

2. Bullom shore showing Cotton Tree village (x) and Cotton Tree *Avicennia* orchard (xx).



Bullom shore showing Yemandugu *Avicennia* orchard (x) and Romboprikon island-orchard (xx).





1. Bullom shore near Tigrin Point showing Kupr *Avicennia* orchard north (x), and south (xx). Kupr village just beyond extreme top right hand corner of print.

2. Kakim Island, south-west portion, showing *Avicennia* orchard (x), and Yelkakrom village on right (xx).

THE CONTROL OF THE CARROT FLY (*PSILA ROSAE*, FAB.) (DIPTERA) WITH DDT.

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Introduction.

In the following account a series of laboratory and field experiments are described in which the newly-discovered insecticidal properties of dichloro-diphenyl-trichloroethane have been tested for the control of carrot fly (*Psila rosae*, F.). This compound was first synthesized by Zeidler in 1874 and is now generally known as " DDT ". A proprietary mixture " Guesapon " (Geigy) declared to contain 5 per cent. DDT was also used in some of the experiments.

Section I.

Control of Carrot Fly by " Guesapon."

In a series of experiments carried out in Switzerland, Wiesmann obtained very satisfactory results with the proprietary emulsion " Guesapon " for the control of carrot fly. For the 1st generation one application of 0.5-1.0 per cent. Guesapon in water was required and for the 2nd, one application of 2.0 per cent. Guesapon. The emulsion was applied by watering can at the rate of 4 litres per sq. metre when the emergence of flies was at a maximum. The mode of action was claimed to be that of a soil insecticide, the newly-hatched larvae being killed whilst moving down to the roots.

A series of experiments was carried out to test the performance of Guesapon under field conditions in East Anglia. Treatments were given during the peak emergence periods and the concentrations and quantities of emulsions recommended by Wiesmann were used together with variations of these.

In one experiment, carried out at the Field Station, Cambridge, both 1st and 2nd generation treatments were done on the same block of carrots. These were sown on 24th March and consisted of 32 plots each containing 5 rows of carrots 1 ft. apart and 4 yards long. The distance between the plots was 30 ins. For the 1st generation experiments half plots only were used (10 row yards), and Guesapon was applied by watering can on 22nd May at 1 per cent. and 4 per cent. strengths and 4 litres per sq. metre. There were 5 replicates of each treatment distributed at random. On 10th July a sample of 50 carrots was taken from each plot, and the damage recorded was as follows (Table I):

Table I.
Control of 1st Generation of Carrot Fly by " Guesapon."

Treatment	Attacked roots %	Mines per 100 carrots	Unsaleable roots %
Guesapon 1%	5·2	5·2	0
Guesapon 4%	1·6	1·6	0
Control (watered) ...	10·8	13·2	1·2

These results show that 4 per cent. Guesapon at 4 litres per sq. metre (approx. 6 pints per sq. yd.) caused a considerable reduction in the 1st generation attack. The 1 per cent. emulsion was much less effective.

For the second generation single and double applications of Guesapon emulsion were used; the dates of treatment and concentrations used are shown in Table II. In all cases the emulsion was applied at 4 litres per sq. metre (as recommended by Wiesmann) except for treatment 8, where it was used at half this rate. Water at the full rate was put on the control plots (Table II).

TABLE II.

Control of 2nd Generation of Carrot Fly by " Guesapon " (Sampled 3rd November).

Treatment				Average Infestation	
Number	Generation 1 22nd May	Generation 2		Attacked roots %	No. of mines per 100 cts.
		26th July	9th August		
9	Water	Water	—	29·4	45·8
6	4%	—	—	17·2	21·6
5	—	3%	—	12·0	15·2
2	—	1%	1%	10·8	13·2
1	1%	1%	—	8·8	12·8
3	—	2%	—	8·8	11·2
7	—	4%	—	8·8	9·6
8	—	4%*	—	7·6	8·8
4	—	2%	2%	6·5	8·0

* emulsion applied at ½ rate—2 litres per sq. metre.

There were 5 plots of each treatment, those of treatments 1, 2, 3, 4, 6 and 7 being of half-plot size and the remainder (5, 8 and 9) of full-plot size. The emulsions were applied by watering can, thoroughly wetting the carrot foliage and the soil to a depth of about 2½ inches. No damage to foliage or roots appeared to follow treatment. On 3rd November a sample of 50 carrots was taken from each of the 45 plots and half-plots and the infestations recorded are also given in Table II. Treatments are arranged in order of attack; 2nd generation damage only was recorded.

Statistical analysis of the results showed that all the Guesapon treatments were significantly better (p. $<$·05) than the controls and that all receiving Guesapon for the 2nd generation were not significantly different from each other (" t " test). There would therefore appear to be little difference in effectiveness between these treatments, all giving on an average 72.5 per cent. control (as mines per 100 carrots) of a moderate infestation. Reference to treatment 6 shows that one application of 4 per cent. Guesapon, applied in May, caused a marked reduction in the 2nd generation attack, thereby indicating that its activity had been maintained for some 3-4 months after application.

The high rate of application of the emulsion recommended by Wiesmann and used in the previous experiment (4 litres per sq. metre or 3,560 gallons per acre) appeared to be a considerable disadvantage in the practical use of this treatment. An experiment was therefore carried out in which a 4 per cent. emulsion was applied to the carrot row only at the rate of one pint per row yd. (With rows 18 in. apart this equals about 1,250 gals./acre.) Furthermore the emulsion was applied either to the carrot foliage causing a thorough wetting of this with a slight run-off or to the soil on either side of the row, the leaf bases and dead foliage on the soil being wetted but most of the emulsion penetrating the soil around the roots. These positions of treatment will now be referred to as " tops " and " roots " respectively.

For this experiment 2 blocks of April-sown carrots A and B were used, each consisting of 21 rows 18 in. apart and each 8 yds. long. Each block was subdivided into 7 plots, each consisting of 3 adjoining rows. In each block 2 plots were " tops " treated, 2 plots " roots " treated, with the remaining 3 receiving a similar quantity of water (controls). Treated and untreated plots were arranged alternately. Block A was treated on 26th July and again on 9th August, whilst block B was treated on 26th July only. Samples of 50 carrots per plot taken from both blocks on 6th November gave the following results (Table III).

TABLE III.

Relative effectiveness of 4% Guesapon applied to " Tops " and " Roots ".

Rate per application: 1 pint per row-yd. Sampled 6th November.

Block	Treatment	No. of plots	Attacked roots %	No. of mines per 100 carrots
A. Treated 26th July and 9th August.	Tops ...	2	4	5
	Roots ...	2	13	17
	Control ...	3	27	37
B. Treated 26th July ...	Tops ...	2	11	19
	Roots ...	2	18	32
	Control ...	3	35	64

The data show that a double application of 4 per cent. Guesapon was more effective than a single dose and that, in both cases, it was more efficacious to apply the emulsion to the foliage than to the soil around the roots.

A third plot experiment was carried out in a field of carrots on fen soil using 4 per cent. and 2 per cent. Guesapon in dyke water. The emulsions were applied at 4 litres per sq. metre on 25th July before flies of the second generation began emerging. There were 2 plots of each treatment and 3 control plots arranged alternately; each measured 8 sq. yds. Samples taken on 6th November from the 4 per cent., 2 per cent. and untreated plots showed the following infestations (per cent. attack) 41.5, 56.0 and 65.3 respectively; the corresponding values of mines per 100 carrots being 62.5, 96.0 and 120.0.

Discussion of Results.

In the three experiments described Guesapon gave an unsatisfactory control of carrot fly infestations. Although the emulsion shows undoubted insecticidal properties, certain results suggest that these are not exerted chiefly through the soil as implied by Wiesmann. In experiment I a graded series of control might have been expected corresponding to the amounts of Guesapon applied. The superiority of the foliage treatment over that of the soil (experiment II) is hardly what might be expected from Guesapon as a soil insecticide.

It became known, however, in the course of the 3 experiments that the Guesapon contained 5 per cent. DDT. This chemical was found by other tests to be very toxic to the carrot fly and to be very persistent in spray deposits on carrot foliage (see sections II and III). This made it clear that the arrangement of plots in the 3 experiments, although suited for testing a soil insecticide, was quite unsuitable for testing the performance of a chemical toxic to the adults, which takes some 12 hrs. or longer to give a complete kill. The small size and close proximity of the various plots must have allowed flies to pass freely from plot to plot, " untreated " flies probably being able to oviposit on treated plots before being affected by the insecticide, whilst " treated " flies, passing to untreated plots, would die in a few hours. An example of this appears to be the considerable and consistent difference between the 2 sets of controls in the " roots " and " tops " experiment. For the single treatment block (B) the control plots had as mines per 100 carrots 66, 70 and 56 respectively. Corresponding values for the double treatment block (A) were 30, 38 and 42. Both blocks of carrots were equally well placed in relation to shelter.

The very similar results given by all Guesapon concentrations for the control of the second generation in experiment I would appear to be due to the influence of neighbouring plots on each other with the Guesapon acting chiefly as an adult insecticide through its DDT residue on the carrot foliage.

To prevent such interaction treated plots should be isolated from each other and from other untreated carrots. They should also be sufficiently large to prevent swamping of results by flies which oviposit within a short time of arrival. The plots by Wiesmann were larger than in the above experiments, each measuring about 11 yds. square, but they were located in the same field and apparently adjoining.

With these limitations the Guesapon method of control, as advocated by Wiesmann, would appear to be unsatisfactory for use on small plots in gardens or allotments. A more promising method under these conditions would be the use of 1-2 per cent. DDT emulsion sprayed on the carrot foliage and surrounding shelter at about fortnightly intervals during the emergence periods of the carrot fly.

SECTION II.

Laboratory Experiments with DDT.

Preliminary tests showed that DDT was highly toxic to carrot fly. A series of laboratory experiments was therefore carried out to determine its effectiveness as an insecticide and its persistence under experimental treatment and outside weather conditions.

The DDT was used in all cases in an emulsion. To prepare this, DDT and a suitable dispersing agent were dissolved in Xylene in the following proportions :*

20 gms. DDT (commercial).
2 gms. Cyclohexylamine dodecyl sulphate.
58 gms. Xylene (Xylol).

This mixture, a miscible oil, gives a very stable milky emulsion with water; 40 gms. of the mixture with 960 gms. of water gives an emulsion containing 1 per cent. DDT. There is a tendency for the emulsion to cream upwards after standing a few days, but the cream disperses readily on stirring or shaking.

Technique.

This emulsion was applied to vegetation either by a hand syringe fitted with a fine nozzle or by a nasal atomiser. Sufficient spray was applied to give a complete cover of the upper leaf surfaces with little run-off. The emulsion has good wetting properties and no difficulty was found in obtaining a full cover. In all experiments the spray was allowed to dry on the leaves, etc., before insecticidal or other tests were carried out.

The insecticidal tests were carried out in hurricane lamp glasses standing on a glass plate, and made fly-proof at the top with a single thickness of buttermuslin. Inside each glass six to eight carrot or potato leaves were supported in a small tube of water which was held by wax to the glass plate. The leaves were arranged loosely so that they touched the sides and top cover of the lamp glass, thus providing the flies with easy access to the vegetation from the container walls.

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* The writers are much indebted to Dr. H. Martin, Long Ashton Research Station, for supplying the above formula and also for a prepared sample of the mixture.

Ten carrot flies were found to be a convenient number to use in each lamp glass. The flies were mostly obtained by sweeping untreated carrot fields and were therefore a mixed population with regard to age and sex. On capture, the flies were stored (usually overnight) in kali bottles with a sprig of vegetation. Only vigorous flies were used, and by replication of the treatments consistent results were obtained. The flies under test were graded into three categories, live, groggy and dead. " Groggy " is a wide concept used to describe flies that have become incapacitated; the degree of incapacity ranging from the flies being merely unstable on their legs and capable of short flights, to lying on their back or side showing feeble uncoordinated leg or wing movements. Flies made groggy by DDT are usually distinguished by their behaviour from uncontaminated flies, and these differences are briefly described later. No groggy flies were found to recover and in most of the records the percentages of dead and groggy individuals have been added under the heading " Percentage Elimination."

The experiments were carried out under room conditions, the temperature prevailing at the beginning and end of an experiment, when recorded, being given in the Tables. The presence of living vegetation in the lamp glasses ensured the flies an atmosphere of high humidity, a condition known to favour their longevity. After some 30 hours, however, high mortalities were frequently encountered in the untreated glasses (controls). Records were therefore usually taken 6 hours and 24 hours after the experiment had been set up.

Results of Experiments.

(1). Carrot tops growing outside at Cambridge were sprayed by a hand syringe with 1 per cent. DDT emulsion on 4th August, 1944. Samples were collected at intervals and tested for insecticidal properties in the manner described. The results expressed as percentage elimination are given in Table IV and figures 1 and 2.

TABLE IV.

Kill of Carrot Fly given by Carrot Leaves treated with 1 per cent. DDT on 4th August. All records as per cent. elimination.

No. of days between treatment and testing	No. of replicates of each treatment	6 hours Record		24 hours Record		Temps. at beginning and end of Expt. °C.
		DDT leaves	Untreated leaves	DDT leaves	Untreated leaves	
0	1	80·0	3·0	100	33·5	22·2—24·2
5	5	48·6	3·0	100	33·5	22·2—24·2
15	1	66·7	10·0	—	—	—
22	4	44·0	17·5	100	35·0	21·5—22·0
26	4	55·0	15·4	100	30·7	21·0—21·5
33	4	38·8	7·9	82·4	31·6	—
40	4	7·7	0·0	48·0	18·0	17·0—19·0
47	4	25·0	5·4	83·4	52·8	19·0
64	5	0·0	0·0	33·3	14·0	13·6—15·0

The tops were exposed from 4th-18th August to a period of intense sun, with maximum shade temperatures from 75.5° F. to 86.8° F., and with an average of 8.9 hours' sunshine per day. A week of much lower temperatures and heavy rains followed, 60.9 mm. (= 2.40 inches) falling in the period 18th-24th August. From this time until the end of September the weather was mostly cool with rain at frequent intervals. The results show that the killing power of the foliage, measured after 24 hours (fig. 2), remained at a maximum for 26 days following treatment despite exposure to extreme conditions of sunshine and rain. After this period the toxicity then declined, but it was still marked some 64 days after treatment. The high mortalities occurring in the 47-day test would appear to be due to using flies of comparatively poor vitality. Records taken 6 hours after introduction (fig. 1) show the marked reduction of toxicity after 26 days, and they also indicate that deterioration of the spray deposit was continuous from the time of application.

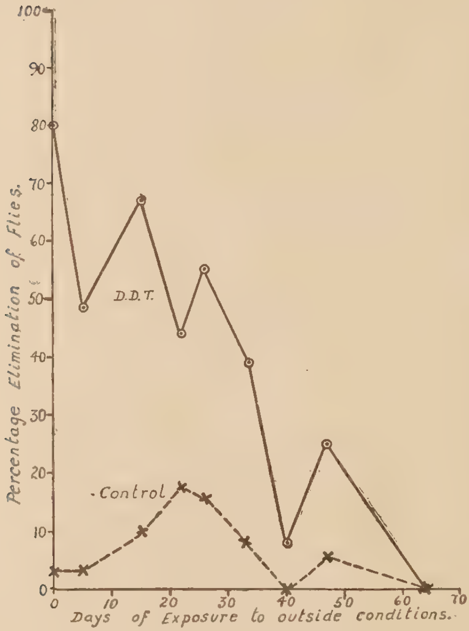

FIG. 1.—Carrot foliage treated 4th Aug., 1944, with 1 per cent. DDT emulsion. (6 hour record.)

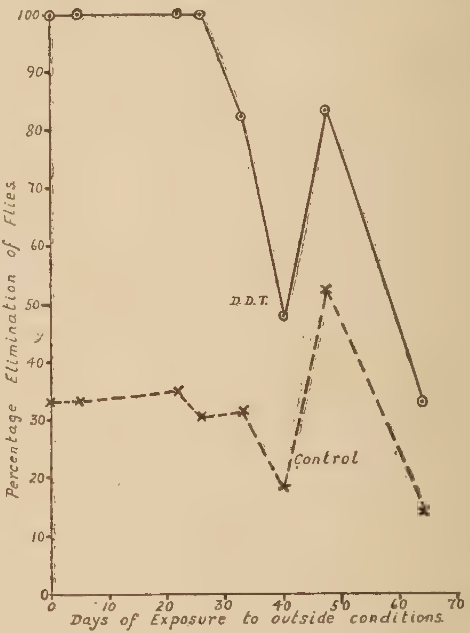

FIG. 2.—Carrot foliage treated 4th Aug., 1944, with 1 per cent. DDT emulsion. (24 hour record.)

In another experiment with carrot foliage sprayed with 1 per cent. DDT emulsion and fully exposed to outside weather conditions, the spray deposit remained fully effective (24-hour record) for 19 days after application; after this it became increasingly less effective. The 6-hour records again indicated that the deterioration had occurred over the whole period of the experiment.

(2). The resistance of the spray deposit to water was also investigated. Carrots with foliage intact were transplanted into eleven large earthenware pots. Pots 1, 2, 3, 4, had the foliage treated with ½ per cent. DDT emulsion, pots 5, 6, 7, 8 with 1 per cent. DDT emulsion and pots 9, 10 and 11 were left untreated (controls). Pots 1 and 2 and 5 and 6 were watered copiously every two days, the foliage being thoroughly swamped from above. The other four treated pots, 3, 4, 7, 8, were kept with the foliage dry, only the soil being moistened. The three controls were given sufficient water to prevent wilting of the foliage, and all pots were protected from rain by placing them in a covered insectary. Foliage was taken from the pots 7 and 14 days after the DDT had been applied, and tested for toxicity to carrot flies in the manner previously described. The results are shown in Table V.

TABLE V.

Resistance of DDT Spray Deposits to Water.

Foliage treated 29.viii.44.

1st Test 6.ix.44. (7 days after treatment.)

Treatment	Pot No.	3·5 hr. Record percentage			6·5 hr. Record percentage			24 hr. Record percentage		
		L.	G.	D.	L.	G.	D.	L.	G.	D.
½% DDT watered ...	1, 2	60	40	0	35	42·5	22·5	0	2·5	97·5
½% DDT dry ...	3, 4	46·2	48·7	5·1	10·2	56·4	33·4	0	2·5	97·5
1% DDT watered ...	5, 6	62·5	32·5	5·0	30·8	59·0	10·2	0	0	100
1% DDT dry ...	7, 8	22·5	75·0	2·5	10	80·0	10·0	0	0	100
Control watered ...	9, 10, 11	76·3	21·1	2·6	65·8	23·7	10·5	37·9	18·9	43·2

2nd Test 13.ix.44. (14 days after treatment.)

Treatment	Pot No.	4 hr. Record percentage			7 hr. Record percentage			27 hr. Record percentage		
		L.	G.	D.	L.	G.	D.	L.	G.	D.
½% DDT watered ...	1, 2	70	22·5	7·5	20·5	59·0	20·5	2·6	5·2	92·2
½% DDT dry ...	3, 4	77·5	20·0	2·5	35·9	38·5	25·6	5·3	5·3	89·4
1% DDT watered ...	5, 6	45·0	37·5	17·5	7·5	55·0	37·5	0	0	100
1% DDT dry ...	7, 8	51·3	43·6	5·1	23·1	46·2	30·7	0	0	100
Control watered ...	9, 10, 11	94·7	5·3	0	94·7	5·3	0	65·7	5·3	29·[illegible]

L = live G = Groggy D = Dead

4 replicates of each treatment at each test.

In the 7-day records the "dry" foliage appears to have been more rapidly effective than the "wet," whilst by the 14-day record the reverse is suggested. There was, however, no outstanding difference between the final kill of the "dry" and "wetted" foliage despite the latter's having received 6 heavy waterings when tested on the second occasion. Similar results were obtained over a 7-day period in another experiment. These findings, together with those obtained in Experiment (I), indicate that this DDT spray deposit is held tenaciously by the carrot leaf surface.

Evidence suggesting that deterioration of the deposit proceeds more rapidly when it is exposed to natural weather conditions than when it is protected from rain and direct sunlight was however obtained. In one experiment 2 plots of carrots in the field were treated with 1 per cent. DDT emulsion, one plot on 4th August and the second on 7th August. Carrots were removed from each of these plots on 17th August, placed in an insectary and their foliage not subsequently treated with water. On 30th August samples of foliage taken from the 4 sets of carrots, namely, the 4th August treated, insectary and field foliage, and the 7th August treated, insectary and field foliage, gave the following mortalities (dead only) of carrot fly in 24 hours: (4th Aug.) 100 per cent. and 90 per cent. and (7th Aug.) 90 per cent. and 78.4 per cent. respectively. However, the results for percentage *elimination* at 24 hrs. are: (4th Aug.) 100 per cent. and 100 per cent., and (7th Aug.) 95 per cent. and 89.3 per cent. respectively. These show that the deterioration has been slight, the change being in speed of kill rather than in total (final) kill.

(3). *Persistence of DDT on Dead Foliage.*—Carrot foliage sprayed with 1 per cent. DDT emulsion and allowed to become air-dry in an insectary was tested 32 days after spraying, for insecticidal properties. The kill given in 24 hrs. by this material was 100 per cent. as compared with a 37.5 per cent. mortality by dead untreated foliage of similar age. There were four replicates of each treatment.

These results show that the spray deposit is persistent after death of the foliage, a property that should considerably enhance its effectiveness in the field.

(4). *Persistence of DDT on Potato Foliage.*—Two plots of potatoes in the field were sprayed with 1 per cent. DDT emulsion, one on 4th and the second on 7th August. Samples of leaves taken from both plots on 30th August and tested in the manner described gave the following results.

Table VI.

Persistence of DDT on Potato Leaves.

Date of treatment	No. of days between treatment and testing	Tested 30th August		No. of replicates
		6 hrs. record per cent. elimination	23 hrs. record per cent. elimination	
4th August ...	26	25·0	90·0	4
7th August ...	23	21·0	89·5	4
Untreated ...	—	21·6	35·2	4

Comparison with Table IV shows that the spray deposit retains its killing power on potato foliage almost as well as on carrot foliage, both being exposed to field conditions.

(5). *Effect of DDT Concentration on Toxicity of the Spray Deposit.*—The relative effectiveness of the spray deposits given by 1 per cent. and ½ per cent. DDT emulsions on carrot foliage under experimental conditions is shown in Table V. At the 7-day test both gave 100 per cent. elimination (groggy and dead) in 24 hrs. but the ½ per cent. was the slower in producing this mortality. In the 14-day record the ½ per cent. strength gave an incomplete elimination (groggy and dead) in 27 hours as compared with a complete kill in this time by the 1 per cent. strength.

The relative efficacy of the two concentrations under field conditions was also tested. Plots of carrots were sprayed with 1 per cent. and ½ per cent. DDT emulsions on 29th August and the foliage tested 8 and 15 days afterwards. The results are shown in Table VII.

Table VII.

Persistence of Spray Deposits given by 1 per cent. and ½ per cent. DDT Emulsions on Carrot Foliage in the Field. Treated 29.viii.1944.

Tested	DDT conc.	Per cent. elimination	
		6 hrs. record	24 hrs. record
6.ix.44	1 per cent. ½ per cent. Untreated	42·1 22·5 7·9	94·8 85·0 31·6
13.ix.44	1 per cent. ½ per cent. Untreated	42·5 38·5 0·0	92·0 83·0 18·0

4 replicates of each treatment at each date of testing.

From both of these experiments it will be seen that the eliminating power, in 24 hrs. of the ½ per cent. deposit is only slightly inferior to that of the 1 per cent. In records taken at less than 24 hrs. the divergence is greater, suggesting that the main difference between the two concentrations is their speed of action. Some 45 hr. records were obtained and these strongly indicated that, in the first few weeks following application, the ½ per cent. spray deposit can produce the same absolute kill as the 1 per cent. but a longer period is required. These deductions are supported by the field cage experiment (see Section III) in which the 1 per cent. and ½ per cent. strength gave similar high kills of carrot fly and other insects under field conditions for a period of four weeks after application.

(6) *Exposure Tests.*—Information concerning the length of time necessary for a carrot fly to spend in contact with a DDT-treated surface to obtain a lethal dose, was obtained in the following manner. The inside of a tube was wetted with a 1 per cent. DDT emulsion and dried at room temperature. Ten flies were then rapidly sucked into the tube and, by moving the tube in relation to the source of light, they were induced to walk almost continuously on the treated surface. After a measured period inside the tube they were rapidly transferred to a kali bottle with untreated fresh vegetation. The control flies were put through a similar but untreated tube; both sets appeared little harmed by this treatment.

The results of one experiment, in which the period of exposure to the spray deposit ranged from ½ min. to 5 mins. are shown in Table VIII.

TABLE VIII.

Relation of Carrot Fly Mortality to Time of Exposure to DDT.

Period of exposure to DDT (min.)	3 hrs. record % elimination	7¼ hrs. record % elimination	24½ hrs. record % elimination
0	10·3	13·8	31·0
½	13·8	21·4	68·0
1	55·2	65·5	89·5
2½	60·0	66·7	83·5
5	46·5	68·0	96·5

3 replicates of each treatment. Temp. at beginning and end of experiment, 18·75° C. and 14·50° C.

These data show that contact with the spray deposit for a period of 1 min. or longer results in very high mortalities. Other experiments were done at room temperature which confirmed this. Furthermore, the rate of elimination or final mortality was not markedly greater with exposure periods of 2½ or 5 mins. than with a 1-minute period. Exposure for ½ min., however, gave a very incomplete kill. This suggests that there is probably a minimum period of contact necessary for the fly to obtain the lethal dose of DDT. Under the conditions of the experiments previously described this would appear to be about 1 min. This period will probably vary somewhat according to the physical conditions of the environment and to the varying resistance of the flies.

(7). *Mode of Action and Effect of DDT on Carrot Fly.*—DDT appears to act against carrot fly as a contact insecticide and is probably absorbed from the substratum through the legs, there being well developed pulvilli on the 5th tarsal segment. Flies were carefully observed during the exposure tests and were not seen to extrude the proboscis on to the spray deposit or to clean the legs with the proboscis, either whilst being exposed or subsequently on the clean vegetation. Furthermore the very low vapour pressure of solid DDT at ordinary temperatures is unlikely to affect the insect, taking into account that high fly mortalities were obtained both in laboratory and field conditions.

As pointed out by several authors (Froelicher (1944), Annand (1944)), DDT is not a quick acting insecticide. With carrot fly its effect becomes apparent from 1 to 2 hours after treatment; they become rather weak, are unstable on their legs and make short erratic flights. These symptoms become intensified until they are unable to fly or stand; they then lie on their side or back kicking their legs or on their back making rapid wing movements. The latter condition has been observed in other Diptera affected by DDT in the field. Under laboratory conditions death usually ensued from 6 to 24 hours after treatment.

SECTION III.

Performance of DDT Spray Deposits in Cages in the Field.

As the experiments described in the previous Section indicated that DDT spray deposits remain active on foliage for several weeks, an experiment was set up to test this in the field. A field of early May-sown carrots, on fen soil at Hall Farm, Mepal (Isle of Ely) was chosen, as at one end the crop had sustained a heavy late 1st generation carrot fly attack (ovipositing in late June and in July). On this area ten fine mesh wire emergence cages were erected on 25th August. Each measured 3 ft. by 1½ ft. and 2 ft. high, and when placed along the rows covered 2 row-yds. of carrots (rows 14 ins. apart), the foliage remaining intact. Emergence of the 2nd generation flies had already started and flies were abundant on the field when the cages were erected. The treatments were carried out on 25th August, three cages were treated with 1 per cent. DDT emulsion, 3 with ½ per cent. DDT emulsion and 4 were untreated. In each cage the carrot tops were thoroughly sprayed and the walls of the cage up to 1 foot above the ground were also wetted with DDT emulsion. About ½ litre of spray was used for 3 cages. The 4 control cages were not sprayed with water as there had been a considerable rainfall on the previous day.

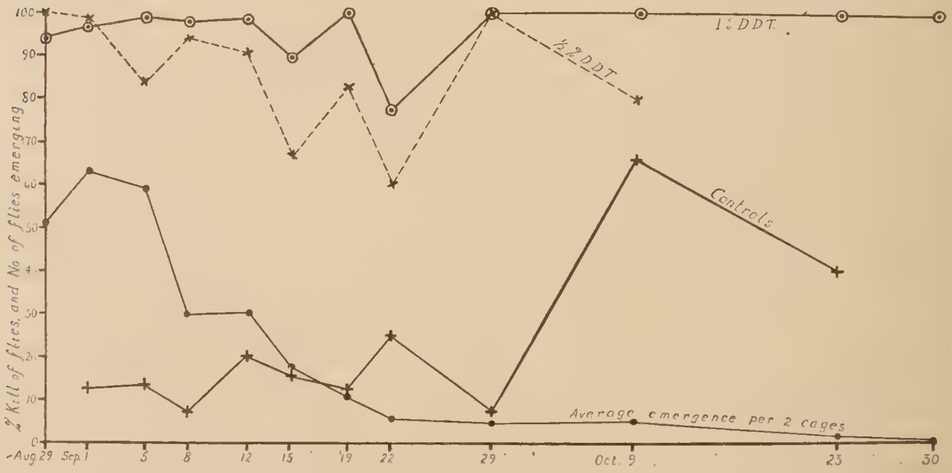

FIG. 3.—Percentage kill in 3 sets of cages, and average emergence per 2 cages.

For the month following treatment the cages were examined at 3 or 4 day intervals. After this, with the slowing up of the rate of emergence the interval was longer. At each examination all live and dead carrot flies were removed, the live individuals being placed in kali bottles with a sprig of untreated vegetation, for transport. Further mortality in these was recorded 12 hrs. later and is included in the figures for total kills. The results obtained from the 3 sets of cages are shown graphically in Fig. 3.

It will be seen that both concentrations of DDT gave very high kills throughout the period of the experiments. The 1 per cent. DDT, however, was more effective than the half strength, the difference becoming increasingly marked during the period 12-22 September. After this a lengthening of the period between the cage examinations to 7 days resulted in both DDT treatments giving a complete kill. That this should occur indicates that deterioration of the spray deposits had taken place, making necessary a longer period of exposure to give high mortalities. Temperature was probably also a contributory factor, being lower in the field at the end of September than at the beginning, thereby reducing both the activity of the flies and probably also of the spray deposits. As only small numbers of flies emerged in October, little value can be placed on small differences between treatments at this time.

A high mortality is recorded for the controls for 29th August. This did not occur in the cages whence a total of 4 dead and 101 live flies were removed but was incurred in the kali bottles through exposures to strong sunlight, and dryness. (On subsequent occasions all bottles were protected against these extreme conditions.) If records for this date are omitted, then the average kill of flies per cage over the two months covered by the experiment gives a fair comparison of the performance of the treatments. These are set out in Table IX.

TABLE IX.

Average Emergence and Kill of Flies per Cage over Period 1st September–30th October.

Treatment	Total alive	Total dead	Dead %
1% DDT	4	115	96·6
½% DDT	15	107	87·7
Control	91	15	14·2

Throughout the period of the experiment all other dead insects found in the cages were collected and preserved. The total numbers obtained in the 1 per cent. DDT, ½ per cent. DDT and untreated cages were 431, 404 and 36, respectively. The comparatively high numbers always found in the treated cages left no doubt that DDT was toxic to a wide range of insects. In fact, with the exception of a springtail (*Entomobrya* sp.) which appeared to be unaffected, the carrot foliage and soil surface were practically sterile of insect life in the treated cages. The state of the dead insects often rendered identification difficult, but the majority found in the treated cages are listed in Table X. It includes many insects, or nearly related forms, injurious to crops, and also some which are beneficial since they attack noxious insects.

Although Aphids were not recorded in the treated cages, they became very common on the carrot foliage at the end of October in all the untreated cages. As all cages were similar in construction it would appear that the Aphids were either deterred by the treated foliage or that an original nucleus (or a subsequent infestation) had succumbed to the DDT. Tests carried out in the laboratory with the cabbage aphis (*Brevicoryne brassicae*, L.) showed that it is killed by contact with a DDT spray deposit. An exposure test also showed that individuals in the "groggy" condition, through DDT, may lay eggs or give rise to living young and that the latter, if placed on untreated leaves, appear healthy and grow rapidly. These field and laboratory observations indicate that treatment of a carrot crop with DDT will not, by killing parasites and predators, predispose that crop to attack by Aphids.

TABLE X.

NUMBERS OF INSECTS KILLED IN DDT-TREATED CAGES.

HEMIPTERA.		
HETEROPTERA:	Lygaeidae (*Heterogaster* sp.)	5
	Anthocoridae	4
	Capsidae	10
	Unclassified nymphs	8
HOMOPTERA:	Jassidae	4
	Cercopidae	2
	Total	33

COLEOPTERA.	
Carabidae	172
Hydrophilidae	2
Silphidae	4
Staphylinidae	129
Histeridae	3
Coccinellidae	21
Scarabaeidae	21
Chrysomelidae	15
Curculionidae	32
Total	399

HYMENOPTERA.		
SYMPHYTA:	Tenthredinoidea:	
	Tenthredinidae	3
APOCRITA:	Ichneumonoidea:	
	Ichneumonidae	3
	Braconidae*	14
	Chalcidoidea	10
	Cynipoidea	1
	Proctotrypoidea	9
	Formicoidea	5
	Sphecoidea (*Crabro* sp.)	1
	Total	46

DIPTERA.		
NEMATOCERA:	Cecidomyiidae	40
	Mycetophilidae	48
	Bibionidae	8
	Chironomidae	9
	Culicidae	3
	Trichoceridae	8
	Tipulidae	1
BRACHYCERA:	Stratiomyidae (larvae)	1
	Therevidae (larvae)	18
	Dolichopodidae	8
	Lonchopteridae	3
CYCLORRHAPHA:	Syrphidae	2
Acalypterae:	Trypetidae	1
	Geomyzidae	35
	Drosophilidae	8
	Oscinidae	15
Calypterae:	Anthomyiidae	56
	Tachinidae	4
Unidentified Cyclorraphous larvae		2
	Total	270

OTHER INSECTS.	
Dermaptera (*Forficula auricularia*, L.)	35
Psocoptera	4
Neuroptera (Chrysops larvae)	2
Lepidoptera (Noctuidae, adults)	4
,, (Noctuidae, larvae)	20
Total	65

* Hymenoptera, Braconidae: includes 7 *Dacnusa gracilis*, Nees, a parasite of the Carrot Fly.

SOME INSECTS OF ECONOMIC IMPORTANCE KILLED IN THE CAGES.

Harmful	*Beneficial*
Forficula auricularia, L.	*Coccinella 7-punctata*, L.
Lygus pabulinus, L.	*Coccinella 11-punctata*, L.
Pterostichus vulgaris, L.	*Halyzia 22-punctata*, L.
Helophorus rugosus, Ol.	*Dacnusa gracilis*, Nees
Blitophaga (Thanatophilus) opaca, L.	*Syrphus luniger*, Mg.
Cassida nebulosa, L.	
Sitona lineatus, L.	

Besides the insects enumerated, numbers of spiders (Arachnida, Araneida), woodlice (Crustacea, Isopoda) and centipedes (Chilopoda), were also found dead in the treated cages. It is not known if these were killed by direct contact with or by ingestion of treated vegetation, or through feeding upon other insects killed by the DDT.

On 30th October, when the cages were removed, one sample of soil and carrots was taken from each of the treated cage sites and from 3 of the 4 untreated sites. Each sample consisted of 1 foot length of row and the soil up to 3 ins. on either side of the row to a depth of 5 ins. The carrots were examined for larvae and graded for damage caused by 2nd generation larvae (*i.e.* the progeny of the flies emerging in the cages). The soil was washed over a 60-mesh per inch sieve and the insects separated by differential flotation in saturated salt (sodium chloride) solution. The following results were obtained (Table XI).

Table XI.

Larval Populations under DDT treated and untreated Cages.
3 samples for treatment taken 30.x.44.

Treatment	Carrots				Soil
	Clean roots %	Unsaleable roots %	No. of mines per 100 carrots	No. of larvae per 100 carrots	Total larvae for 3 samples
1% DDT ...	84	0	16	13	7
½% DDT ...	87	0	13	5	6
Untreated ...	51	6	79	38	13

Comparing both larval populations and damage, the two DDT treatments are not significantly different. In both however, the numbers of larvae and mines are very much lower than in the untreated samples. The removal of all flies from the untreated cages at 3 to 4 day intervals during the peak emergence period was in itself an effective method of preventing reproduction and subsequent damage. Under favourable conditions carrot flies do not normally oviposit until some 3 days after emergence whilst in the cool weather of late September and in October, this period would be considerably longer. A series of samples typical of many taken in this area over a number of years was obtained on 23rd October from an untreated plot of carrots growing 200 yds. from the cage sites. These showed an infestation of 108 mines per 100 carrots and 216 larvae per 3 ft. of row (in the soil and carrots). Of the latter some 47.9 per cent. were immature as compared with 3.3 per cent. immature on the untreated cage sites. This shows the attack in the latter to be very abnormal both in intensity and larval size distribution for this area and time of year. It is therefore very probable that the DDT treatments were much more effective than comparison with the untreated data would suggest. In conclusion, it can be stated that the 1 per cent. and ½ per cent. DDT sprays gave over 95 per cent. kill of carrot fly for a month after application and that the resulting maggot attack was slight.

Section IV.

A Field Trial with DDT.

Whilst carrying out the experiments described in Sections II and III, it became apparent that a small scale field trial would provide valuable information of the performance of DDT under semi-commercial conditions. Accordingly 7 lb. of DDT were made up into 140 gallons of emulsion using solvent naphtha instead of Xylene as the solvent. This emulsion, ½ per cent. DDT in strength, was applied to 2⅓ acres of carrots, a rate of about 50 gals. per acre. The carrot field used for the experiment was that in which the cages experiment (Section III) was carried out. The area sprayed adjoined the cages and had been heavily damaged by a late 1st generation attack. On the remainder of the field this attack had been comparatively slight. The emulsion was put on by a mobile power-operated machine delivering spray through fine nozzles at high pressure. Treatment was carried out on 15th September, a good cover of the foliage was obtained, and the spray was dry after about 10 minutes. Flies were abundant on the field at the time and had been for a month previously (see fig. 3). Observations made 30 minutes after treatment (air temp. 72° F.) showed that many carrot flies and other adult Diptera were affected by the spray and in a groggy condition.

To assess the abundance of flies in this area sweeping was done before treatment, 2 hrs. afterwards and subsequently at intervals of a few days until 13th October. All live flies taken were placed in kali bottles with untreated vegetation and the mortality in these ascertained 12 hrs. later. Similar sweeping and mortality records were obtained from the untreated end of the same field and from a carrot field wholly untreated, some 400 yards to the east. The latter was sown in late May and incurred a late first generation attack less heavy than that on the treated area of the first field. The results obtained from the treated area and from the wholly untreated field are shown graphically in fig. 4.

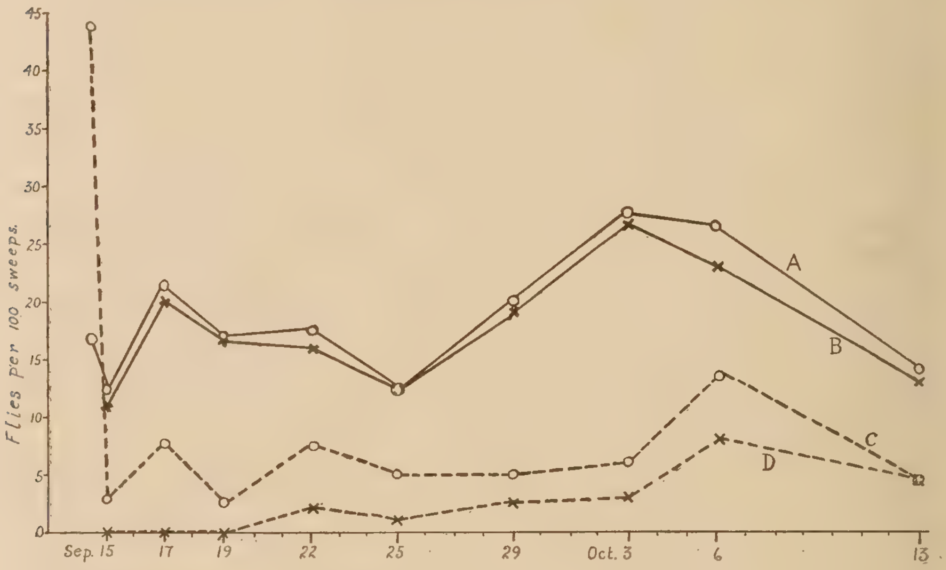

FIG. 4.—Abundance and viability of flies on DDT-treated and on untreated field.

The upper curve (A) records the abundance of live flies as swept in the untreated field. The mortality after 12 hours in a sample of these was recorded, and using these results, the field abundance figures were partitioned into "live flies" and "flies which died." The figures for "live flies" are given by the curve (B) and they show that throughout the experiment a low mortality occurred in flies from the untreated field. The two lower curves are the abundance curve (C) and the "live flies" curve (D) for the treated area. They show that, in the comparatively small numbers of flies taken, a high death rate occurred in 12 hours. In fact, for the first three records taken 2 hours, 2 days and 4 days after spraying, probably all the flies on the DDT area were either dead or potentially so. The first records shown for the untreated and the treated field were obtained 3 hours before spraying was done. On the untreated area adjoining that treated by DDT, the flies maintained a high level of abundance and showed low mortalities throughout, as on the wholly untreated field. From the graph it will be seen that there was a rise in abundance and a decline in the mortality of flies from the treated area on 6th October. On 13th October the mortality of flies taken in this area was nil. The decline in effectiveness of the treatment was not entirely attributable to a deterioration of the spray deposit but was in part due to the growth of vegetation, particularly of weeds, since the time of spraying. Such untreated foliage would provide a safe shelter for flies emerging in the area and for those drifting in from outside.

Besides the sweeping records, counts were made of the dead carrot flies and other insects found on both treated and untreated fields. Two days after spraying

4 quadrats on the treated and 2 on the untreated field, each measuring 1 sq. yd. and taken at random, were examined. The following records were obtained (Table XII).

TABLE XII.

Mortalities of Carrot Fly and other Insects on treated and untreated Fields.

Replicates each 1 yd. × 1 yd.	Treated Field				Untreated Field	
	a	b	c	d	x	y
Carrot Flies dead ...	9	3	6	10	2	0
,, ,, alive ...	0	0	0	0	3	1
Other insects dead ...	26	38	41	37	1	0

The range of other insects killed was similar to that given in Table X with Capsids (chiefly *Lygus pabulinus*), Jassids, Lepidopterous caterpillars and Acalypterate Diptera, the most commonly represented groups. Quadrats were again examined on 13th October, 4 weeks after spraying. On the treated area recently killed carrot flies and other insects were common with considerably larger numbers in a state of decay. Live insects (except springtails) were scarce. On the untreated field, however, no dead carrot flies were found and live insects of many kinds were abundant.

Although the emergence of the 2nd generation on this field was more than half completed when the DDT was applied, the elimination of many of these flies and of those emerging later could be expected to reduce the infestation greatly on the treated area. Accordingly 5 samples, each comprising 1 ft. of carrot row and the associated soil, were taken at random from the DDT area and from the untreated field. The damage and larval population on these were as follows (Table XIII).

TABLE XIII.

Comparison of Damage and larval Populations on DDT-treated and untreated Fields. 2nd generation damage only recorded. Sampled 8th November.

Treatment	No. of carrots in 5 samples	Carrots roots undamaged per cent.	Roots unsaleable per cent.	No. of mines per 100 carrots	Total larvae in soil and carrots for 5 samples
DDT-treated area ...	68	44	0	96	73
Untreated field	75	16	33	265	287

Not only was there a big difference in the damage and larval populations between the two samples but also there was a much higher proportion of very small larvae in the samples from the untreated field than from the treated. This indicates that the difference in damage on the two fields would further increase with time.

Discussion.

From the experiments described, it appears that DDT will be a very valuable weapon for combating infestations of the carrot fly. Its toxicity to the adults and permanence on foliage under all weather conditions give it undoubted advantages over the sodium fluoride-molasses mixture now in commercial use. The latter is readily removed by rain, needs frequent renewal and is fully effective only in warm dry weather conditions. A DDT spray, however, of ½-1 per cent. concentration, having dried on the carrot foliage, should remain fully toxic to carrot fly alighting thereon, for a period of at least three weeks after application. With vegetation possessing a strong waxy cuticle into which the DDT may be absorbed this period may be shorter. Where the cuticle is thin, however, as with carrot and potato foliage, the rapid growth of vegetation in spring and summer will probably necessitate re-spraying after 14 days to maintain a high percentage of treated vegetation in the shelter. The number of applications required for each carrot fly generation can only be determined by further field experiments.

Summary.

(1) The proprietary emulsion "Guesapon", containing 5 per cent. DDT, gave an unsatisfactory control of carrot fly damage on a plot scale.

(2) Treatment of the carrot foliage with this emulsion was more effective than treatment of the soil.

(3) A 1 per cent. emulsion of DDT applied to carrot foliage in the field gave 100 per cent. mortality of carrot flies in the laboratory for 26 days after treatment and showed marked toxicity after a further 38 days.

(4) The DDT spray deposits were very resistant to treatment with water and remained active after death of the foliage. They were also very toxic and lasting on potato foliage.

(5) Deposits given by ½ per cent. and 1 per cent. DDT emulsion were similar in toxicity and persistence. The ½ per cent. is, however, slower in action.

(6) From a treated surface the carrot fly is able to acquire a lethal dose of DDT in a very short time, probably by absorption through the feet.

(7) Emulsions containing ½ per cent. and 1 per cent. DDT applied to carrot foliage under cages in the field both gave 95 per cent. kill of carrot flies for a month after application. The treatments also gave a high kill of other insects.

(8) Soil samples showed that the larval population and the damage was much lower in the treated than in untreated cages.

(9) In a field trial 2⅓ acres of carrots were treated with ½ per cent. DDT emulsion at about 50 gals. an acre.

(10) Sweeping showed a rapid decline in abundance of flies after treatment and high mortalities were observed. These features did not occur on neighbouring untreated carrots.

(11) These effects lasted for some 21 days after treatment and a marked reduction of larval population and damage resulted.

Acknowledgements.

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References.

Annand, P. N. & others (1944). Tests conducted by the Bureau of Entomology and Plant Quarantine to appraise the usefulness of DDT as an insecticide. —J. econ. Ent., **37**, pp. 125-159.

Froelicher, V. (1944). The Story of DDT.— Soap and Sanit. Chem., **20** (7), p. 115.

Wiesmann, R. (1944). Report on Experimental Work.—Geigy Colour Co. Ltd. and Stafford Allen & Sons, Ltd., England.

Zeidler, O. (1874). Verbindungen von Chloral mit Brom- und Chlorbenzol.— Ber. dtsch. chem. Ges., **7**, pp. 1180-1181.

A RAPID FIELD METHOD FOR ASSESSING THE SPREADING POWER OF ANTI-MALARIAL OILS.*

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It is essential that an oil used for killing mosquito larvae on the surface of stagnant water should cover the whole surface completely with a spread film. Only if the oil spreads completely over the surface can it be certain of reaching all the larvae, penetrating into their respiratory system, and so killing them. Although practically all oils (except the most highly refined mineral oils) will spread on *clean* water surfaces, most stagnant waters have surfaces so contaminated by surface films, visible or invisible, that their surface tension is reduced much below that of clean water. This hinders, or completely prevents, spreading of oils of low spreading power which would spread on clean water. Therefore, other things being equal, an oil with a high spreading power is preferable to one with a low spreading power; indeed an oil with a low spreading power may, in practice, be of little or no use. A simple method of determining spreading power is thus of considerable importance.

Spreading power is measured as the force, in dynes per centimetre, which must be applied along the surface to the advancing edge of a drop to prevent it spreading. This force, often called the " spreading pressure," is equal to the diminution of surface tension of the water caused by the presence, on its surface, of a spread film of the oil in equilibrium with a small excess of the oil standing in droplets or " lenses " on the surface. Ultimately, spreading pressure can be measured either by the use of a " film balance," in which the outward spreading force is balanced against a force mechanically applied to a light float which blocks the spreading of the oil, or by measurement of the surface tension of the water when covered by the spread film, with a few droplets of unspread oil present as well. Apparatus for this purpose is well known (*cf.* Adam, 1941, or any good textbook of practical Physics), but is difficult to carry and use in the field or far from a well-equipped laboratory. It is, however, quite easy to carry small quantities of liquids whose spreading power has been determined by one of these methods, and to compare the spreading power of any oil with these standards, simply by placing, in turn, drops of the standards and of the unknown oil on the surface, and observing which spreads against the other, pushing the weaker spreader of the two back into a droplet.

The spreading standards need to be liquids which are involatile and insoluble in water, or at most very slightly soluble or volatile. The principal difficulty is, however, to find reasonably accessible liquids whose spreading power does not vary on waters of different acidity. Those liquids containing appreciable amounts of acids which are insoluble or nearly insoluble in water have a spreading pressure which may vary by ten dynes per centimetre, or more, on waters whose pH varies over the range commonly found among natural waters. This excludes, as spreading standards, all fatty acids, and unfortunately also most vegetable oils, since these generally contain one or two per cent. of free fatty acid, or may develop acidity on storing, especially if exposed to light. Castor oil, sometimes recommended as a spreading standard, has a spreading pressure which varies from less than 20 on water of pH about 5.5, up to more than 30, on pH 8.5; and different samples of this oil differ in the extent to which their spreading pressure changes according to the acidity.

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On the other hand, alcohols, which contain only hydroxyl groups in addition to the hydrocarbon part of the molecule, are quite free from this objection and have a constant spreading pressure on water ranging from acid to alkaline, even considerably beyond the limits of pH of natural waters. The esters of such acids as phthalic and salicylic, whose acids are fairly soluble in water, also have a constant spreading pressure; if traces of acid are present in these esters they are so quickly removed from the interface between the drop of oil and the water that the slight acidity does not affect the spreading power.

As a rule, temperature has but a slight effect on the spreading pressure. Cary and Rideal (1925) showed that liquids usually suffer a very slight decrease in spreading pressure with rising temperature, usually of the order of one dyne per centimetre for ten degrees Centigrade rise in temperature. This change with temperature is small enough to be neglected for all ordinary purposes.

By dissolving a spreading substance in a highly refined, non-spreading mineral oil, such as medicinal paraffin, the spreading power can be adjusted to any desired value. Adam (1937) used solutions of dodecyl alcohol, $C_{11}H_{23}CH_2OH$, in a water-white mineral oil of German origin, which had by itself no spreading power, thus obtaining a range of solutions with spreading power varying from zero up to 22 dynes per centimetre. Norris and Taylor (1938) used ethyl myristate in medicinal paraffin. Dodecyl alcohol and ethyl myristate are not easily available, and the latter substance may easily contain myristic acid.

Terpineol (so-called " liquid " terpineol), though very slightly volatile, is very suitable, with a spreading pressure of 36 dynes per centimetre at 20°C., which may be reduced to any desired extent by dilution with medicinal paraffin. The technical quality of oleyl alcohol, now available in the chemical industry, has a spreading pressure of about 47 dynes per centimetre alone, and is easily soluble in medicinal paraffin. Dimethyl or dibutyl phthalate and methyl or ethyl salicylate are also good standards.

The following Table gives the spreading pressures at 20°C. of the above substances, and also of solutions of terpineol and oleyl alcohol in medicinal paraffin. They have been measured with a film balance, on water or aqueous solutions the pH of which has been varied beyond the limits of 5 to 8.5, and showed no observable change in spreading pressure. Although the paraffin, terpineol, and oleyl alcohol are not pure chemical substances, it is unlikely that specimens of reasonably good quality, from other sources, will have spreading pressures differing from the above values by more than a very few dynes per centimetre.

Standard spreading liquids.

	Spreading pressure, dynes per cm., 20°C.
Methyl salicylate	13
Ethyl salicylate	13
Dimethyl phthalate	21
Dibutyl phthalate	21
Terpineol, liquid (from British Drug Houses, Ltd.)	36
Oleyl Alcohol, technical* (from I.C.I., Dyestuffs, Ltd.) ...	47

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* This specimen of oleyl alcohol had an iodine value of 61·8 and was solid at room temperature; it contained a considerable amount of saturated alcohols, in addition to the unsaturated oleyl alcohol.

Standard Spreading Solutions.

Solvent: B.D.H. Liquid Paraffin, S.G. 0.835/0.850.*

Terpineol in paraffin		Oleyl alcohol in paraffin	
c.c. terpineol in 100 c.c. solution	Spreading pressure. dynes/cm. 20° C.	gm. oleyl alcohol in 100 c.c. solution	Spreading pressure, dynes/cm. 20° C.
0·1	4·5	0·2	12
0·2	7·5	0·5	17
0·5	13	1·0	25
1·0	18	2·0	30
2·0	21	5·0	37
5·0	25	10·0	46
10·0	30		

The concentrations required for any spreading pressure not given in the above table can easily be found by plotting the above figures and interpolating graphically.

Volatile solvents such as benzene, toluene, and even xylene are quite unsuitable, since evaporation is so rapid in the spread film that the concentration increases so fast, with consequent rapid rise of spreading pressure, that accurate results cannot be obtained. Chloroform and ether are still more unsuitable for the same reason.

Method for comparing spreading power.

The spreading pressures of the standards and unknown oil are best compared on clean water surfaces. To obtain clean surfaces, the simplest method is to set up a large glass funnel, preferably not less than eight inches diameter at the rim, over a sink, with the rim horizontal, and to admit water from the bottom through the funnel stem. The water overflows all round the rim, carrying any accidental contamination with it. If the funnel is given a reasonably thorough preliminary cleaning, with soap and water if grease is actually adhering to it, a few minutes running and overflowing of the water as above leaves the surface practically clean for a long time after the inflow is discontinued. Chemical cleaning with chromic acid is unnecessary, but if soap is used, care must be taken to run the water sufficiently long to remove all traces of soap, which is a powerful depressant of surface tension.

After running in water from the stem, the supply is stopped, and a very little tipped out of the funnel, so as to lower the level just below the rim. A small quantity of one of the liquids (standard or unknown oil) is placed on the surface, sufficient being used to leave at least one drop about a quarter of an inch across remaining after the spread film has covered the whole surface. The exact amount of excess liquid is not important, but if solutions are used, it should not be less than this. If, as often happens, the liquid spreads violently at first to a film which breaks up into a large number of small drops, the total excess unspread should not be less than the above quantity.

Having spread one liquid, a drop of the other is then put on the surface. If it remains as a lens or droplet of small area, the second liquid has a smaller spreading pressure than the first. Some idea of the difference between the spreading pressures can be obtained, after a little experience, from the shape of the second, unspread drop; if it spreads a little way, to a flat, thin drop with a very acute angle at the rim, its spreading pressure is not much less than that of the drop first applied. If it remains very compact, with a fairly large angle between its upper and lower surface at the rim, its spreading power is considerably below that of the first liquid.

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* Most water-white paraffin preparations of "medicinal" quality are equally suitable, provided that they do not spread on clean water surfaces. Kerosene or industrial paraffins are quite unsuitable as solvents for spreading standards, since they vary greatly in composition and also spread themselves on water.

If the second liquid spreads, pushing back the film of the first liquid and displacing the film first spread from the surface, the second liquid has the higher spreading power. The rate of spreading of the second drop is some guide as to the difference in spreading pressure, a rapid spread indicating a large difference in spreading pressure; but since the rate of spreading depends on the viscosity of the liquid as well as on the spreading pressure this alone is not a reliable guide. Successive trials should be made with a number of spreading standards, the water surface and funnel being cleaned between each trial, until two standards are found, one a slightly more powerful, the other a slightly less powerful, spreader than the unknown oil. Comparison can, in practice, be made with an accuracy of about two dynes per centimetre.

There is usually little doubt whether spreading has occurred, but spreading can be made much more obvious if the surface is lightly dusted, before the test, with talc (French Chalk); a tube with a paper cover pricked with small holes is convenient for holding the talc. Talc does not usually contaminate a water surface at all; if necessary, it can be cleaned by boiling with strong nitric acid or aqua regia, and washing and drying.

Cleaning between tests can be done without dismantling the funnel; any oil adhering to the rim can be quickly removed by rubbing with the finger, two or three times, using a little soap, which is then washed away with a rapid stream of water. Naturally the soap is more readily washed away than adhering oil.

Occasions may arise when the spreading power must be tested directly on the stagnant water where the larvae may breed. If this surface is small in extent, *e.g.* puddles, one comparison can be made on each puddle; a second trial on the same puddle will be difficult on account of the first two oils used adhering to the sides. For water from ponds, the funnel technique can be used, if a small tank is arranged from which the pond water can run into the stem of the funnel; of course the tank must be free from all grease. In all these tests, great care must be taken to avoid accidental contamination of the water surfaces; it must always be remembered that oil from a previous test, or a perspiring finger dipped for a moment into the surface, will cause a film of grease to spread and cause serious contamination. Wading into a pond is almost certain to contaminate it, unless it is already heavily contaminated; and the films are usually invisible.

References.

Adam, N. K. (1937). Proc. roy. Soc., (B) **122,** p. 134.

—— (1941). The Physics and Chemistry of Surfaces. 3rd ed. Oxford. Chaps. II and IX.

Cary, A. & Rideal, E. K. (1925). Proc. roy. Soc., (A) **109,** p. 318.

Norris, A. & Taylor, T. W. J. (1938). J. Chem. Soc., **1938,** p. 1719.

THE RESIDUAL TOXICITY OF DDT TO BED-BUGS (*CIMEX LECTULARIUS*, L.).

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Introduction.

The purpose of the investigation described below was to determine the residual toxicity of DDT to bed-bugs (*Cimex lectularius*, L.) when it was applied to the surface of materials commonly used in the construction of buildings; at the same time, a comparison was made between the residual toxicity of DDT and that of other insecticides. The bed-bug, because of its wide distribution and its habit of infesting surfaces, either exposed or hidden, is an eminently suitable test insect for such an investigation.

Material and Technique.

The bugs used throughout this work were obtained from a laboratory culture* kept at 25°C. and fed weekly on rabbit blood. The sample of DDT used was the pure para para compound, free of isomers, with melting point 109°C.

Blocks of the materials to be treated, measuring approximately 2 in. × 2½ in., were sprayed in a tower, originally devised by Potter (1941), with different volumes of DDT dissolved in a mixture of nine parts of odourless distillate† and one of ethylene dichloride to give varying deposits of DDT per square centimetre of surface.‡ Forty-eight hours later, when the blocks had dried at room temperature, bugs were exposed on the sprayed surface for 24 hours; they were then transferred to clean recovery tubes and kept at 25°C. for a period of six days, at the end of which mortality counts were made. During the intervals between subsequent tests, the blocks were hung on a wall of the laboratory, facing a window and therefore exposed to any strong sunlight, and left undisturbed at ordinary room temperature.

Residual Toxicity of DDT to Bed-bugs.

(a) *Toxicity when applied to certain materials.*

The following materials were sprayed with varying quantities of a 4 per cent. solution of DDT to give different deposits of DDT per sq. cm. of surface, and their insecticidal power tested 48 hours, 1, 3 and 6 months after treatment:

1. Keen's cement;
2. Plain unpainted deal wood, sawn across the grain;
3. Deal wood which had been painted some years previously (composition of the paint is not known);
4. Deal wood painted with the following composition three weeks before spraying with DDT solution:
    White lead
    turpentine
    putty driers
    Oxford ochre;
5. Plain glass.

A minimum of six blocks of each material was used for a single test and six to eight bugs were exposed on each block at the intervals specified above. Table I summarises the percentage mortalities given at these intervals by the various materials after they had been treated with different deposits of DDT per sq. cm.

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* The bugs comprising this culture were originally collected from the London area.

† A refined light oil, slightly above paraffin cut. S.G. ·779 ; B.P. 200°C. ; flash point (closed), 71°C. ; viscosity, Redwood I, 32 sec. at 20°C.

‡ 1 cc. of this mixture sprayed in a Potter tower gave a deposit of approximately 0·36 mg./cm².

TABLE I.

Per cent. mortality of bugs given at intervals by materials treated with DDT. (In this and in all subsequent tables, the numbers of bugs from among which each per cent. mortality was obtained, is given in brackets.)

Deposit of DDT (mg./cm.^{2})	Tested at intervals of :	Keen's cement	Plain wood	Old painted wood	Newly painted wood	Glass
0·23 ...	48 hours ...	100 (30)	100 (30)	100 (30)	44 (30)	
	1 month ...	94 (30)	97 (30)	94 (30)	40 (30)	
	3 months...	80 (30)	77 (30)	63 (30)	20 (30)	
	6 ,, ...	63 (27)	65 (26)	17 (28)	22 (27)	
0·12 ...	48 hours ...	93 (30)	83 (30)	79 (30)	37 (30)	
	1 month ...	83 (30)	80 (30)	73 (30)	37 (30)	
	3 months...	57 (30)	60 (30)	47 (30)	13 (30)	
	6 ,, ...	56 (27)	59 (27)	12 (24)	11 (27)	
0·06 ...	48 hours ...	80 (30)	86 (30)	89 (30)	28 (29)	100 (30)
	1 month ...	77 (30)	88 (30)	83 (42)	26 (35)	97 (32)
	3 months...	53 (30)	60 (30)	43 (30)	11 (36)	100 (32)
	6 ,, ...	33 (27)	38 (27)	12 (25)	4 (23)	—
0·03 ...	48 hours ...	70 (30)	70 (31)	69 (29)	32 (28)	90 (30)
	1 month ...	60 (30)	70 (30)	63 (30)	8 (36)	90 (36)
	3 months...	47 (30)	43 (30)	43 (30)	13 (36)	79 (24)
	6 ,, ...	32 (25)	32 (28)	11 (27)	0 (21)	67 (18)
0·01 ...	48 hours ...	70 (30)	79 (31)	66 (30)	17 (30)	93 (32)
	1 month ...	43 (30)	47 (30)	40 (30)	3 (36)	70 (30)
	3 months...	52 (30)	50 (30)	7 (30)	8 (36)	76 (30)
	6 ,, ...	0 (27)	29 (27)	9 (23)	0 (25)	48 (27)
0·007 ...	48 hours ...					80 (35)
	1 month ...					53 (30)
	3 months...					69 (33)
	6 ,, ...					—
0·004 ...	48 hours ...					73 (30)
	1 month ...					31 (32)
	3 months...					29 (24)
	6 ,, ...					—

The figures in this Table demonstrate that

(i) as might be expected, the bug mortalities at each of the specified intervals were generally higher at the heavier DDT deposits;

(ii) a minimum deposit of 0.23 mg. of DDT per sq. cm.* was necessary on cement, plain wood and old painted wood to yield 100 per cent. mortality. Forty-eight hours after treatment, a similar deposit on newly painted wood yielded a relatively low mortality, whereas on glass one-fourth of that deposit sufficed to give a complete kill;

(iii) the toxicity of the different surfaces one month after treatment with the heavier deposits of DDT (0.06 to 0.23 mg. per sq. cm.) diminished only slightly, if at all; with the lighter deposits, particularly on newly painted wood, toxicity fell considerably;

(iv) three months after treatment with deposits of DDT ranging from 0.007 to 0.06 mg. per sq. cm., glass still gave a minimum kill of 70 per cent.; of the remaining surfaces, cement and plain wood alone give a similar kill, and then only at the heaviest dosage employed, *viz.*, 0.23 mg. DDT per sq. cm.;

(v) six months later, cement and plain wood were still partially effective, giving approximately 60 per cent. mortality at the maximum dosage; a slightly higher mortality was given by glass at a dosage as low as 0.03 mg. per sq. cm.

(b) *Effect of disturbing a surface treated with DDT.*

During the course of the above tests, it was observed that bugs exposed on glass and painted wood forty-eight hours after the surface had been treated with the heavier deposits soon became covered with DDT crystals. This suggested that any subsequent fall in toxicity of the treated surface might be explained simply by the fact that less DDT was available to bugs used in later trials on that same surface. To confirm this, blocks of old painted wood were sprayed with either 8 cc. or 1 cc. of a 4 per cent. DDT solution to give DDT deposits of either 0.12 mg. or 0.01 mg. per sq. cm., respectively, and were left unused for one month before their toxicity was first tested. Blocks treated with the heavier deposit yielded 72 per cent. mortality, and with the lighter, 48 per cent. Reference to Table I shows that these figures do not differ appreciably from the percentage mortalities given by old painted wood submitted to a *second* test one month after treatment with similar doses of DDT. It may be inferred, therefore, that it is the minute crystals of DDT, not visible to the naked eye, which are responsible for its toxicity, both immediate or persistent, and that the large crystals which the insect may pick up have little or no lethal effect. The question then arose whether these minute crystals would be retained by a particular surface even after it had been subjected to treatment with a duster. Blocks of old painted wood were sprayed with a 4 per cent. DDT solution to give a deposit of either 0.12 mg. or 0.01 mg. DDT per sq. cm. After drying, they were rubbed vigorously before their toxicity was tested. Blocks with the heavier deposit yielded 88 per cent. mortality, and with the lower, 66 per cent.; when tested after a second rubbing given a week later, the mortalities had fallen to 20 per cent. and 19 per cent., respectively. A similar result was obtained with glass. Pieces of glass, sprayed to give a deposit of 0.06 mg. of DDT per sq. cm. and then tested at intervals extending over three months, gave 100 per cent. mortality at the end of this period; they were then rubbed and washed with cold water to remove all visible traces of DDT, and when retested proved to be completely non-toxic. Thus, it seems that an ordinary household duty such as dusting or washing is sufficient to remove the majority, if not all, of the small crystals of DDT from a smooth surface and so reduce its toxicity considerably.

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* x mgs. of DDT per sq. cm. is approximately equivalent to 930 x mgs. per sq. ft.

(c) *Time exposure necessary for bed-bugs to acquire a lethal dose of DDT.*

The following tests were carried out to ascertain the minimum period of exposure to DDT necessary for the insect to acquire a lethal dose. Bugs were exposed for intervals varying from 15 mins. to 24 hours on filter papers which had been impregnated with a solution of DDT in a volatile solvent (acetone) to give different average deposits of solute per square centimetre of surface.* The results, summarised in Table II, suggest that exposures of more than one hour did not definitely yield an increase in percentage mortality, and it appears, therefore, that this was the critical period during which the insect acquired a lethal dose of DDT.

TABLE II.

Per cent. mortality of bugs according to time exposure on filter paper treated with DDT.

mg. DDT/cm.^{2} Time of exposure	1	3	5	10
¼ hour	—	—	55 (20)	81 (16)
½ ,, ...	6 (16)	12 (16)	80 (15)	100 (18)
1 ,, ...	25 (16)	44 (16)	81 (16)	94 (16)
2 hours	11 (35)	12 (32)	78 (38)	100 (38)
24 ,, ...	30 (20)	40 (20)	79 (19)	100 (25)

The question then arose whether or not this critical period was constant irrespective of the material used. The preceding test was therefore repeated on both glass and unpainted wood treated in a similar manner to give different average deposits of DDT per square centimetre of surface. The results obtained are summarised in Table III.

TABLE III.

Per cent. mortality of bugs according to time exposure on (*a*) wood and (*b*) glass, treated with DDT.

Deposit of DDT (mg./cm.^{2}) Time of exposure	WOOD			GLASS		
	1	5	10	1	5	10
5 minutes	—	—	—	23 (30)	33 (30)	55 (18)
15 ,, ...	—	—	—	16 (31)	42 (36)	70 (20)
½ hour	23 (60)	33 (57)	47 (60)	33 (60)	37 (37)	66 (66)
1 ,, ...	37 (30)	64 (28)	93 (30)	43 (30)	52 (30)	90 (38)
2 hours...	38 (30)	69 (29)	84 (30)	47 (29)	57 (29)	100 (21)
6 ,, ...	37 (30)	66 (30)	94 (30)	48 (30)	50 (30)	80 (15)
24 ,, ...	40 (30)	70 (30)	100 (30)	47 (15)	47 (15)	100 (15)

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* The minimum volume of acetone necessary to ensure that the filter paper was evenly wetted, was ascertained. This volume, containing different concentrations of DDT, was then distributed as quickly as possible over the surface of the filter paper to give the average deposits stated.

The results show that after exposure of one hour on both wood and glass, treated with DDT, there is, again, no *consistent* and marked increase in percentage mortality at any of the DDT deposits tested. The individual percentage mortalities, however, given in Tables II and III, are based on small numbers of bugs. Moreover, among the bugs exposed on the treated surfaces, some, presumably would remain stationary while others would wander in varying degree, and the extent to which this difference in behaviour might influence the final percentage mortalities has not yet been ascertained. For these reasons, the results obtained do no more than suggest that *if* the insect acquires a lethal dose of DDT, it does so within a definite period of exposure, namely, one hour, and that this period is constant irrespective of the nature of the treated material on which the insect is exposed.

The percentage mortalities were surprisingly low among bugs exposed for 24 hours on glass and plain wood treated with DDT dissolved in acetone to give either 1 or 5 mgs. of DDT per sq. cm. As shown in Table I, among bugs exposed for a similar period on these materials 48 hours after their surfaces had been sprayed with DDT dissolved in odourless distillate to give a DDT deposit as light as 0.06 mg. per sq. cm., a mortality of 86 per cent. was obtained on plain wood and 100 per cent. on glass. This apparent discrepancy suggested that the toxicity of a material sprayed with DDT in a slowly volatilising solvent is greater than the toxicity of the same material impregnated with DDT in a rapidly volatilising solvent. (Odourless distillate ostensibly evaporates only within 48 hours, acetone within 15 minutes.) To confirm this, filter papers, because they were more easily available than either glass or plain wood, were impregnated with DDT, dissolved in odourless distillate to give average deposits of DDT per sq. cm. of either 1 or 5 mgs. To ensure complete evaporation of the solvent, the papers were left for three days at room temperature; bugs were then exposed on them for 24 hours. On papers treated with the lighter deposit, 82 per cent. mortality was obtained, and with the heavier, 100 per cent. A comparison of these percentage kills with those obtained among bugs exposed for the same period on filter papers impregnated with DDT dissolved in acetone to give similar average deposits demonstrates that the initial toxicity of a surface treated with DDT solution is determined, at least to some extent, by the volatility of the solvent used.

In the immediately preceding tests, bugs were exposed to a *dry* deposit of DDT. The next step was to ascertain whether the period of exposure necessary to produce an effective kill could be curtailed if DDT was available on a surface in the form of an oil-solution film. A further series of filter papers was therefore impregnated to give a deposit of 1 mg. of DDT per sq. cm. Each of these papers was halved and one-half was sprayed with odourless distillate to give oil deposits of either 0.36, 1.44 or 2.88 mg. per sq. cm., while the other half was left untreated with oil. Bugs were then exposed on these papers, dry and oil-sprayed, for either half an hour or twenty-four hours, and in the control series, for the same periods on non-impregnated filter papers sprayed to give similar deposits of odourless distillate. The results of these tests, summarised in Table IV, demonstrate that (i) the toxicity

TABLE IV.

Per cent. mortality on dry and oil films of DDT.

Time exposed	1 mg./cm.² DDT				Odourless distillate only (mg./cm.²)		
	Dry	Sprayed with odourless distillate (mg./cm.²)					
		0·36	1·44	2·88	0·36	1·44	2·88
½ hour ...	7 (30)	53 (30)	57 (30)	100 (30)	0 (30)	0 (30)	0 (30)
24 hours ...	33 (30)	80 (30)	100 (30)	100 (30)	0 (30)	3 (30)	3 (30)

of odourless distillate, even after twenty-four hours exposure, is negligible; (ii) over a given period, DDT is more toxic to bugs when available as an oil solution than as a dry deposit. For instance, among bugs exposed for half an hour on a dry film of DDT (1 mg. per sq. cm.) there was 7 per cent. mortality, but after the same exposure on a similar film sprayed with odourless distillate, mortality increased to 53 per cent.; likewise, after twenty-four hours' exposure on an oil film mortality was 80 per cent. as compared with 33 per cent. on a dry film.

(d) *Oil spraying of a DDT-treated surface as a means of prolonging its effectiveness.*

The results of the tests described in the preceding paragraph were of theoretical rather than practical interest, since it obviously would not be convenient to maintain an oil film on the wall of a room which was constantly inhabited. But one possible practical application suggested itself, namely, oil-spraying of a DDT-treated surface the toxicity of which had been reduced by rubbing away the superficial deposits of DDT. It was thought that by this method any residual DDT which had not been removed by rubbing and which was not highly toxic as a dry film might dissolve in the oil and so prolong the effectiveness of the treated surface. The blocks of old painted wood, the toxicity of which had been reduced by rubbing, as described on page 275, were therefore sprayed with odourless distillate to give an oil deposit of either 0.18 or 0.09 mg. per sq. cm., and their toxicity then tested. Several days later the same blocks were tested after they had again dried and then after they had been sprayed a second time with odourless distillate. Control blocks, not previously treated with DDT, were sprayed to give similar deposits of oil. Table V embodies the percentage mortalities given by these blocks after two dustings and then after having been sprayed on two successive occasions with oil.

TABLE V.

Original deposit of DDT (mg./cm.^{2})	Mortality after one rubbing	Mortality after 2 rubbings	Mortality after 1st spraying with oil (mg./cm.^{2})		Mortality after drying	Mortality after 2nd spraying with oil (mg./cm.^{2})	
			0·18	0·09		0·18	0·09
0·12	88% (32)	20% (30)	67% (30)	60% (35)	16% (30)	13% (30)	13% (30)
0·01	66% (30)	19% (26)	58% (24)	17% (30)	9% (24)	9% (24)	0% (30)
0	—	—	0% (30)	0% (30)	—	0% (30)	0% (30)

A comparison of the figures in columns 3 and 4 of this table demonstrates clearly that the low toxicity of the rubbed surface was greatly enhanced when that surface was sprayed to give an oil deposit as light as 0.18 mg. per sq. cm. Such a fine oil film would not be a serious inconvenience in an inhabited room, and its evaporation after 48 hours would allow ample time for bugs to come in contact with it.

The Efficiency of DDT compared with that of other Insecticides.

During the present year biological assays have been made of the toxicity to bed-bugs of a large number of substances which were either isomers of DDT or had structural formulae analogous to it. Of these, one only, di-(4-methoxyphenyl) trichlorethane (referred to below as S13) was a toxic, when used as a direct spray, as DDT. It was considered desirable, therefore, to ascertain whether its *residual* toxicity also approached that of DDT; at the same time its effectiveness, both as a direct and as a residual spray, was compared with that of certain other insecticides. Two series of trials were accordingly undertaken: (i) different concentrations in odourless distillate of DDT, S13, pyrethrum extracted in kerosene,* crude benzene hexachloride (referred to as 666/107)† and Lethane 384 Special‡ were sprayed directly on to bugs to give varying deposits of active principle per sq. cm. of surface; (ii) blocks of Keen's cement were sprayed with either a 10, 5, 1 or 0.5 per cent. solution of the insecticides named in (i) to give deposits of active principle ranging from 0.6 to 0.004 mg. per sq. cm. The insecticidal property of the blocks was tested at intervals of twenty-four hours, three weeks and seven weeks after spraying and those which then yielded a minimum mortality of 50 per cent. were tested five months after spraying. Table VI summarises the percentage mortalities given by the different insecticides when used as direct sprays, and Table VII, when used as residual sprays. In both tables, the figures indicating deposits of active principle refer to total pyrethrins in the case of pyrethrum, to the γ isomer in the case of 666/107, and to the thiocyanates in the case of Lethane 384 Special.

TABLE VI.

Per cent. mortalities given by different insecticides when used as direct sprays.

Insecticide / Deposit of active principle (mg./cm.^{2})	DDT	S13	Pyrethrum	666/107	Lethane 384 Special
0·04	—	—	—	—	39 (44)
0·004	91 (36)	100 (30)	—	—	—
0·002	67 (63)	71 (35)	—	—	—
0·0004	—	—	100 (38)	100 (20)	—
0·0002	—	—	—	82 (34)	—
0·00004	—	—	60 (38)	—	—

A comparison between the figures given in these two tables shows that (i) when used as a direct spray, pyrethrum gave complete mortality at one-tenth of the concentration of DDT and S13 necessary to give a similar kill; twenty-four hours after use as a residual spray it was still more effective than either DDT or S13, but whereas the toxicity of these latter two was still considerable seven weeks later, that of pyrethrum was negligible. (ii) Of the insecticides tested, DDT, S13 and 666/107 only gave at least 50 per cent. kill at the heavier deposit seven weeks after application, and of these three, 666/107, when used at approximately one tenth the specified dose of DDT and S13 was the most effective both as a direct spray and for 24 hours after use as a residual spray, but after five months it was completely ineffective. DDT and S13 on the other hand were equally effective both as direct and as residual sprays and showed some degree of toxicity five months after application. (iii) Lethane 384 Special was relatively ineffective against bugs as a direct spray, even when used at ten times that concentration of DDT which gave a high mortality; as a residual spray its initial toxicity was comparable to that of DDT but again only when it was used at ten times the specified concentration of the latter. Seven weeks after application its toxicity was only comparable to that of DDT when used at one twentieth of the concentration of Lethane 384 Special.

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* The total pyrethrin content (wt./vol.), assayed by Mr. W. A. L. David, was: Pyrethrin I 2·45 per cent.; Pyrethrin II, 2·25 per cent.

† i.e. the unground, undiluted plant product containing the following isomers in the proportions indicated: α, 70 per cent., β, 5 per cent., γ, 12 per cent. and δ, 7 per cent., by weight. Of these, the γ isomer is the toxic element and was first described by Slade (1945) under the name Gammexane. The sample used in this work was kindly supplied by Messrs. I.C.I. (General Chemicals) Ltd.

‡ i.e., 12·5 per cent. β-butoxy-β'-thiocyanodiethyl ether. 37·5 per cent. β-thiocyanethyl laurate. 50 per cent. odourless distillate.

Table VII.

Per cent. mortalities given by different insecticides when used as residual sprays.

Deposit of active principle (mg./cm.²) / Interval after spraying	DDT		S13		Pyrethrum		666/107		Lethane 384 Special	
	0·06	0·03	0·06	0·03	0·06	0·03	0·007	0·004	0·6	0·3
24 hours	85 (24)	47 (30)	83 (24)	50 (24)	100 (24)	100 (24)	100 (24)	71 (24)	93 (24)	33 (24)
3 weeks	90 (24)	50 (24)	70 (24)	63 (24)	17 (24)	13 (24)	80 (24)	70 (24)	43 (24)	13 (24)
7 weeks	83 (24)	37 (24)	80 (24)	43 (24)	13 (24)	8 (24)	63 (24)	24 (24)	43 (24)	0 (24)
5 months: Dry ...	33 (24)	—	44 (30)	—	—	—	0 (24)	—	—	—
5 months: After oil spray...	45 (24)	—	25 (24)	—	—	—	0 (24)	—	—	—

The next step was to find out whether or not the toxicity of a DDT-treated cement surface could be increased, as was the case with painted wood, by application of an oil film. The cement blocks treated 5 months previously with DDT and S13 were therefore sprayed, before further testing, with odourless distillate to give an oil deposit of 0.36 mg. per sq. cm. At the same time, for purposes of comparison, the cement blocks treated 5 months previously with 666/107 were similarly sprayed. The results obtained have been incorporated in Table VII; they show that (i) although an oil film on a DDT-treated surface enhanced its toxicity slightly, it did not do so to the same extent as on painted wood; and (ii) such a film on a cement surface 5 months after it had been sprayed with 666/107, was ineffective, either because (*a*) 666/107 had completely volatilised within that period or (*b*) if present, it had not been brought to the surface by the oil.

Discussion and Summary.

The investigations herein recorded show that DDT is more toxic to bed-bugs when available on a surface as an oil solution than as a dry film, and that the toxicity of the latter is determined to some extent by the volatility of the medium in which DDT is applied. The results of trials on filter paper, glass and unpainted wood suggest that the minimum period of exposure to a dry film of DDT necessary for the insect to acquire a lethal dose is one hour, and that this critical period is constant irrespective of the nature of the DDT-treated material to which the insect is exposed. Tests with bugs on DDT-impregnated filter paper show that this period can be curtailed considerably by the addition of a fine oil spray.

The persistent toxicity of DDT varies according to the nature of the surface to which it is applied. Three months after treatment with DDT (0.23 mg. per sq. cm.) cement and plain wood kill approximately 80 per cent. of bugs exposed thereon; after six months, these surfaces still yield about 60 per cent. mortality. Glass, treated with a deposit as light as 0.03 mg. per sq. cm., yields similar kills at the corresponding periods. Wood, painted many years previously, and treated with the maximum dosage of DDT used, is as toxic to bugs for at least one month after treatment as are cement and plain wood. Its toxicity then falls considerably, and six months after is roughly one fourth that of cement and plain wood at the same interval after treatment. On the other hand, newly painted wood sprayed with an equivalent dosage of DDT is not markedly toxic to bugs, even forty-eight hours after treatment. Lindquist *et al.* (1944), investigating the persistent toxicity to house flies of DDT sprays, record a similar observation.

Persistent as DDT is, the results of the investigations described here do not confirm the far-reaching claims made for it by other workers. Madden *et al.* (1944), exposing a mixed population of *Cimex lectularius*, L., and *C. hemipterus*, F., for forty-eight hours in cages constructed of wood and glass, obtained complete insect mortality approximately two and a half months after the walls and miniature furnishings of the cage had been sprayed with 100-150 mg. of a 20 per cent. solution of DDT per square foot of surface (equivalent to 0.02 to 0.03 mg. DDT per sq. cm.). The precise nature of the surface is not specified but presumably it was chiefly wood and glass. Again, a field trial carried out by the same authors, using a 5 per cent. solution of DDT in kerosene, achieved 100 per cent. mortality three months after the application of DDT to surfaces not specified. The amount of solution applied was 250 mls. but the unit area of surface is not stated; however, assuming it to be a square foot, 250 mls. of a 5 per cent. solution would result in a deposit of 0.013 mg. DDT per sq. cm. My own work shows that, of the materials tested, glass yielded only 76 per cent. mortality three months after treatment with dosages of approximately 0.013 mg. DDT per sq. cm.; the other surfaces similarly treated gave no more than 52 per cent. kill after the same interval. Admittedly, during the present investigations bugs were exposed on the treated surface for a limited period, namely, twenty-four hours, but the percentage mortalities obtained among bugs exposed for different periods on a variety of DDT-treated surfaces suggest that prolonged exposure, which presumably would be achieved in a field trial, does not necessarily yield an increase in percentage mortality.

It is the minute crystals of DDT deposited on a treated surface that are responsible for its toxicity, both immediate and persistent; large crystals which the insect may pick up do not appear to have a marked lethal effect. A solvent which on evaporation deposits DDT in the form of very small crystals should, therefore, prove more economical than one which deposits large crystals. When DDT is applied to *smooth* surfaces, such as glass and painted wood, even the small crystals do not completely withstand simple household operations such as repeated rubbing and washing with cold water. Madden *et al.* (1944), on the other hand, found that cages sprayed with DDT solution and scrubbed a week later with hot water and soap gave complete bug mortality as late as seventy-eight days after treatment. The low toxicity of a rubbed surface can be renewed to some extent by the application of fine oil film indicating that vigorous rubbing does not wholly remove all DDT crystals. Such a film is sufficiently persistent to allow time for contact with bugs and yet, because it evaporates within forty-eight hours, does not constitute a serious inconvenience in an inhabited room.

Of a number of insecticides tested as direct sprays, pyrethrum, contrary to the statement of McGovran *et al.* (1944), was found to be ten times more toxic to bugs than either DDT or its analogue di-(4-methoxyphenyl) trichlorethane. As residual sprays these two latter substances were far more efficient than pyrethrum, giving at least 80 per cent. mortality seven weeks after application as compared with 13 per cent. given by pyrethrum applied at an equivalent dosage. This finding is in harmony with that of Madden *et al.* (1944), but whereas these investigators obtained 60-80 per cent. kills with the equivalent of approximately 0.03 mg. pyrethrum per sq. cm., three weeks after application, my own results suggest that pyrethrum is oxidised far more rapidly, since after the same interval it only gave 13 per cent. kill when applied at the same dosage.

I wish to express my indebtedness to Professor P. A. Buxton, F.R.S., for his kind and helpful criticism of this work, to the Medical Research Council by whom it was financed, and to Dr. J. R. Busvine, Ministry of Health, for many profitable discussions and for his generous co-operation on technical points. My thanks are also due to Mr. N. F. Wilson for his assistance in preparatory work.

References.

Lindquist, A. W., Madden, A. H., Wilson, H. G. & Jones, H. A. (1944). J. econ. Ent., **37**, pp. 132-134.

McGovran, E. R., Richardson, H. H. & Piquett, P. G. (1944). *Ibid.*, pp. 139-140.

Madden, A. H., Lindquist, A. W. & Knipling, E. F. (1944). *Ibid.*, pp. 127-128.

Potter, C. (1941). Ann. appl. Biol., **28**, pp. 142-169.

Slade, R. (1945). Chem. Trade J., **116**, pp. 279-281.

THE EFFECT OF MERCURY VAPOUR ON THE EGGS OF *CALANDRA GRANARIA* (L.) (COL., CURCULIONIDAE).

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Wright (1944) has recently summarised most of the information about the toxicity of mercury vapour to insect eggs. The present work did not arise directly from this, though I was aware of his results, but was undertaken to explain a number of experiments in which *Calandra* eggs failed to hatch both in my own work and in that of members of the D.S.I.R., Pest Infestation Laboratory. These failures were found to be due to accidents such as a broken thermometer releasing a small quantity of mercury into an incubator.

All the experiments were performed at a temperature of 25°C. and a relative humidity of 70 per cent. (unless otherwise stated) and the wheat was all part of one sample of English wheat in equilibrium with the above humidity (*i.e.* water content about 14.2 per cent.). Under these conditions, fertile eggs hatch in about 5 days.

Period which Grain should be kept to determine percentage Hatch.

A preliminary experiment showed that in the absence of mercury about the same percentage hatch is detected when the grain is dissected on any one of the 6th to 10th days.

A number of fertilised female weevils was isolated in 3 × 1 in. glass tubes closed with corks bored with a $\frac{1}{2}$ in. diameter hole. The hole was closed on the inside with a piece of fine-mesh brass gauze held in place by a piece of muslin gripped between the cork and the glass (= tubes with bored corks). For six successive two-day periods these females were allowed to oviposit in two wheat-grains. On alternate days the grains were dissected after soaking for 24 hours in 70 per cent. alcohol and the number of eggs was counted. The females were then arranged in five groups (A-E) of nine weevils which had approximately equal oviposition-scores in the twelve-day testing period. The members of each group (still each in a tube with bored cork) were then given two grains on each of five successive two-day periods. The infected grain obtained in this way was kept for 6, 7, 8, 9 or 10 days, so that the developmental periods were 6-8, 7-9, etc., days. In each group of weevils, grain from a different two-day period was kept for each of the developmental periods as follows:—

TABLE I.

Weevil groups, two-day periods, and time in days for which infected grain was kept.

Two-day period No. ...	1	2	3	4	5
Weevil group—					
A	6	10	9	8	7
B	7	6	10	9	8
C	8	7	6	10	9
D	9	8	7	6	10
E	10	9	8	7	6

The results of the dissections are shown in Table II. It is probable that the apparent differences in fertility between the eggs kept for different periods are due to chance but it is possible that the apparent increase in fertility at 10 (= 10-12) days is due to some infertile eggs having been eaten by growing larvae in the same grain. In the experiments with mercury, the grain was usually kept for 7 (= 7-9) days, or in some cases 10 days before dissection.

TABLE II.

Percentage hatch of eggs in grain kept for varying periods.

A = Numbers of eggs alone ; B = first-stage larva ; C = second-stage larva.

Days grain was kept	6	7	8	9	10	Totals		Per cent. hatched
	A B	A B	A B	A B C	A B C	A B C		
Weevil Group								
A	12 + 26	19 + 30	12 + 29	9 + 34	8 + 27 + 2	60 + 146 + 2	208	71
B	6 + 28	10 + 30	7 + 31	7 + 31	3 + 30 + 1	33 + 150 + 1	184	82
C	6 + 28	8 + 27	4 + 33	13 + 33 + 1	5 + 30	36 + 151 + 1	198	77
D	12 + 27	9 + 28	11 + 24	20 + 24 + 1	8 + 27 + 1	60 + 130 + 2	192	69
E	18 + 32	10 + 27	9 + 31	13 + 27	13 + 28 + 3	63 + 145 + 3	211	70
Totals	54 + 141	56 + 142	43 + 148	62 + 149 + 2	37 + 142 + 7	252 + 722 + 9	983	74
	195	198	191	213	186	983	—	—
Per cent. hatched	72	72	77	71	80	74	—	—

TABLE III.

Oviposition during the preliminary period and in the experimental period of two groups of twelve weevils.

	Test periods						Experimental periods									
	1–4	5–10					Treated grain					Untreated grain				
	No. eggs	Hatched	Devd.	Not hatched	Total	Per cent. hatched	Hatched	Devd.	Not hatched	Total	Per cent. hatched	Hatched	Devd.	Not hatched	Total	Per cent. hatched
Group A	176	269	3	55	327	82·3	178	5	28	211	84·4	173	3	28	204	84·8
Group B	171	239	8	58	305	78·4	159	5	41	205	77·6	170	5	44	219	77·6

Treatment of Grain with Mercury Vapour *before* Oviposition.

Two lots of 200 grains of wheat were placed one layer deep in Petri dishes. The dishes were put in desiccators (volume 1,560 c.c.) containing 75 c.c. of potash solution to give 80 per cent. R.H. In one desiccator (treated grain) was a 3 × 1 in. tube containing 66.2 g. of mercury (surface 4.5 cm^2). These desiccators were kept at 25°C. for 20 days before the grain was used.

The oviposition of a number of fertilised female weevils was tested (in tubes with bored corks on two grains) for ten successive two-day periods; the percentage hatch of the eggs was also recorded for the last six periods. They were then arranged in two groups of twelve and were allowed to oviposit in two grains taken from the desiccators for ten successive two-day periods. Oviposition was at 25°C. 70 per cent. R.H. and each group of weevils was given treated and untreated grain alternately, but when group A had treated grain group B had untreated, and *vice versa*. The results of this experiment are given in Table III. In some eggs the larva develops to the point where the mandibles are visible as black dots but then fails to hatch. Such eggs are termed " developed " (devd.). It is evident from Table III that under the conditions of the experiment pretreatment of the grain has no effect on fertility.

Exposure of Grain containing Eggs to Mercury Vapour for long Periods at 25°C.

It was originally proposed to expose the grain for 10 days, but when this was found to cause complete sterility the length of exposure was gradually cut down in the later batches.

TABLE IV.

Exposure of *Calandra* eggs to mercury vapour for 1–10 days at 25° C. 80 per cent. R.H.

Period of exposure days ...	10	9	7	5	3	1	0 (control)
Eggs not hatched	138	18	22	27	32	26	19
,, developed	3	0	2	1	1	1	7
,, hatched	0	0	0	0	0	0	207
Total	141	18	24	28	33	27	233
Per cent. hatched	0	0	0	0	0	0	88·8

Two groups of six weevils were used to supply the eggs. In a preliminary ten-day testing period they laid 181 (hatch 83 per cent.) and 182 (hatch 88 per cent.) eggs respectively. During the experimental period the grain containing eggs from one group was put all together in an open 3 × 1 in. tube standing in one desiccator, while the grain from the other was similarly put in an open tube in the other desiccator. The desiccators were those used in experiment 2, one with mercury, one without. Thus eggs from each group were exposed to mercury or not exposed (controls) on alternate two-day periods. After grain had been exposed to mercury for three periods in one group and two in the other (*i.e.*, with 2 and 3 controls respectively), the period of exposure was cut down to 9, 7, 5, 3 and 1 days, so that for these shorter exposures only grain from one group laid in one two-day period was available. The results are given in Table IV and show that under these conditions *Calandra* eggs are sterilised in 24 hours or less.

Exposure of Grain containing *Calandra* Eggs to Mercury Vapour for short Periods at 25°C.

A number of fertilised female weevils was tested for oviposition on two grains in tubes with bored corks. After 6 two-day periods, three groups of 15 weevils were made up, chosen so that their oviposition score had been about the same. The groups were then tested for a further 5 two-day periods to estimate their fertility. The eggs laid in three successive two-day periods after this were used for the experiment. The three lots of grain from each group were exposed to mercury vapour once for 24 hours, once for 8 hours and once kept as control with the following schedule.

Period No. ...	1	2	3
Group			
A ...	Control	24 hrs.	8 hrs.
B ...	8	Control	24
C ...	24	8	Control

The grain was kept until the eggs were 8-10 days old before dissection. The same desiccators were used as in experiment 2, but they were thoroughly cleaned and were given a new lot of the same potash solution. To contain the mercury, a 3 × 1 in. tube was cut down so that it was 17.0 mm. high. This was filled with 47.3 g. of clean mercury which came to 8.0 mm. of the rim; as before, the surface was 4.5 cm^2. The results of this experiment are given in Table V. They show that 24 hours' exposure to mercury vapour is almost sufficient to sterilise *Calandra* eggs completely, while an 8-hour exposure only allows 10 per cent. of them to hatch, or, if allowance is made for the 20 per cent. sterility in the controls, 1.4 and 12.6 per cent. A number of larvae which did emerge was found to be dead when the grain was dissected.

Exposure of Grain containing Eggs to Mercury Vapour for one, two and three Days at 10°C.

Since only a little space was available at 10°C., the experiment was carried out in two stages and smaller containers were used (volume 230 c.c., potash solution 30 c.c., mercury arranged as in expt. 4). The eggs were laid by three groups, E, F, and G, of 12, 12 and 13 fertilised female weevils. In the first experiment grain containing eggs was exposed to mercury vapour for 0, 48 and 72 hours, in the second for 0 and 24 hours. The results of the experiment are shown in Table VI.

In this experiment the eggs did not hatch very well even in the controls. Possibly the females had been isolated from males for too long a period. If an allowance is made for about 34 per cent. sterility in the controls, the hatch after exposure to mercury vapour at 10°C. for 24, 48 and 72 hours was 54.2, 12.8 and 7.4 per cent. respectively.

Penetration of Mercury Vapour through Grain at 25°C.

Mercury vapour not only sterilises eggs in grain exposed one layer deep but also reaches to the bottom of culture jars, which may contain grain 6.0-8.0 cms. deep. An experiment was set up to find out what depth of grain could be penetrated at 25°C. in two days. The apparatus used is shown in fig. 1. C was a litre flask, closed with a rubber bung, F; on the bottom of which was 47 g. of mercury, much broken up. B was a glass tube 23.5 mm. internal diameter. It was closed at the top with a cotton wool plug and at the bottom with a waxed cork E. Vapour from the flask was admitted to the bottom of B by a glass tube A through the bung and the cork; the tube was 5.5 cm. long and 6.0 mm. internal diameter. To prevent grain entering A, a piece of coarse cotton netting G was laid over it

TABLE V.

Oviposition and fertility of 3 groups of 15 weevils during preliminary testing and on exposure of the eggs to mercury vapour for 8 and 24 hours at 25° C.

Two-day testing periods							Experimental periods														
1–6		7–11					Exposure 8 hrs.					Exposure 24 hrs.					Control				
Group	No. eggs	H.	N.H.	D.	T.	%H.	H.	N.H.	D.	T.	%H.	H.	N.H.	D.	T.	%H.	H.	N.H.	D.	T.	%H.
A	270	237	42	20	299	79·3	3	38	19	60	5·0	0	58	7	65	0·0	54	7	2	63	86·0
B	285	259	28	16	303	85·5	6	41	15	62	10·0	2	56	1	59	3·0	43	5	3	51	84·0
C	273	181	60	4	245	73·9	9	34	14	57	16·0	0	52	4	56	0·0	48	17	0	65	73·8
Totals ...	—	677	130	40	847	*79·9*	18	113	48	179	*10·1*	2	166	12	180	*1·1*	145	29	5	179	*81·0*

Note.—H. = hatched ; N.H. = not hatched ; D. = developed ; T. = total.

TABLE VI.

Oviposition and fertility of 3 groups of weevils during preliminary testing and on exposure of the eggs to mercury vapour for 0, 24, 48 and 72 hours at 10° C.

Preliminary test (10 days)					First experimental period (6 days, but 16 days later)															Second experimental period (2 days)									
Exposure (hours)	—				0					48					72					0					24				
Group	H.	NH.	T.	%H.	H.	NH.	D.	T.	%H.	H.	NH.	D.	T.	%H.	H.	NH.	D.	T.	%H.	H.	NH.	D.	T.	%H.	H.	NH.	D.	T.	%H.
E	229	36	265	86·4	52	12	7	71	73	6	32	17	55	11	1	46	11	58	2	40	11	9	60	66·7	—	—	—	—	—
F	209	55	264	79·2	29	18	4	51	57	5	25	17	47	11	5	33	10	48	10	—	—	—	—	—	16	16	19	51	31
G	233	32	265	87·9	35	17	3	55	64	2	30	21	53	4	2	52	6	60	3	—	—	—	—	—	21	18	13	52	40
Total ...	671	123	794	84·5	116	47	14	177	*65·5*	13	87	55	155	*8·4*	8	131	27	166	*4·8*	40	11	9	60	*66·7*	37	34	32	103	*33·0*
Allowing for 34·5% sterility														*12·8*					*7·4*	Allowing for 33·3% sterility									*54·2*

Note.—H. = hatched ; NH. = not hatched ; T. = total ; D. = developed ; %H. = per cent. hatched.

on the inside of the cork. D was a short length of capillary tubing to equalise the pressure inside the flask with that of the constant temperature room. The positions 0, 1, 2 and 3 on tube B were 0, 30; 60 and 90 cm. from the netting. Grain containing eggs was placed at these points and the rest of the tube was filled up with clean grain. Before the weevils laid in the grain it had been stained one of three

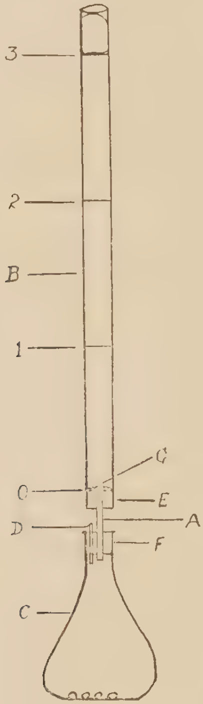

FIG. 1.

colours, red (safranin), crystal violet, methyl green. These vital stains were used at a concentration of 1 g. in 1,000 c.c. of water. They were known not to affect oviposition if the grain was reconditioned to the right relative humidity after staining. Table VII shows how the eggs from the three groups of weevils (the same as in experiment 5) was used.

TABLE VII.

Two-day period No.		1	2	3	4	5	6
Group E	position of grain	0	1	C	2	3	C
	colour	Red	Green	Violet	Green	Violet	Red
Group F	position	1	C	2	3	C	0
	colour	Violet	Red	Green	Red	Green	Violet
Group G	position	C	2	3	C	0	1
	colour	Green	Violet	Red	Violet	Red	Green

C = control, kept in tube with bored cork at 25° C. 70 per cent. R.H.

The eggs were 0-2 days old when put into the tube 3, and were left there for 2 days; after removal from B they were kept at 25°C. 70 per cent. R.H. for 6 days, so the eggs had had a developmental period of 10-12 days. Table VIII shows the results of the experiment.

TABLE VIII.

Effect of mercury vapour on eggs separated from the source by 0, 30, 60 and 90 cm. of grain at 25° C.

Treatment	Un-hatched	Developed	Larvae		Total	Per cent. hatch
			1st stage	2nd stage		
Control	43	22	181	31	277	76·5
Position 0	83	72	4	0	159	2·5
,, 1	33	78	17	0	128	13·3
,, 2	27	5	99	9	140	77·1
,, 3	27	5	89	21	142	77·5

Under these conditions, mercury vapour penetrates through grain to 30 cms., but not to 60 cms., in two days.

Penetration of Mercury Vapour through Grain at 12°C.

The same apparatus was used as in expt. 6. The eggs were laid by the same weevils in one two-day period but the infected grain was all mixed together and then divided into five lots (control and four positions). Both the clean and the infected grain was cooled before putting it into the apparatus. The exposure in the apparatus was for 7 days and after removal it was kept at 25°C. for 8 days. The control grain was kept at 12°C. alongside the apparatus in a tube with bored cork. The results of the experiment are shown in Table IX. It is clear that owing to the longer period of exposure the mercury vapour has penetrated through the 90 cm. of grain.

TABLE IX.

Effect of mercury vapour on eggs separated from the source by 0, 30, 60 and 90 cm. of grain at 12° C.

Position of grain	Not hatched	Developed	Hatched	Total	Per cent. hatched
0	40	3	4	47	9
1	28	3	4	35	11
2	24	7	4	35	11
3	23	8	5	36	14
Control	9	2	35	46	76

Discussion.

The vapour of mercury is extremely toxic to *Calandra* eggs, even at low temperatures and will penetrate in time through a considerable depth of grain. There is a big temperature coefficient, however, for the greater toxicity at 25°C. compared with 10°C., is more than can be accounted for by the different vapour tensions of mercury at the two temperatures, *i.e.* the time-concentration product for a 90 per cent. kill is much larger at 10°C. than at 25°C. The experiments do not exclude the possibility that eggs which have undergone some development become more susceptible, for at 25°C. two days is nearly half the incubation period, whereas at 10°C. the eggs hardly develop at all even in three days.

It seems clear that the vapour has in part a delayed action, because of the difference in the numbers of " developed eggs ", *e.g.* in Table V. In the 8-hour exposure, it is seen that 26.8 per cent. of the eggs develop. It might have been expected that in the 24 hour exposure 26.8 per cent. would have developed in the first eight hours and then have been killed. But the actual figure for developed eggs is 6.7 per cent. The more probable hypothesis, therefore, is that no development occurs while the eggs are actually exposed to the vapour, but a certain amount, depending on the length of the exposure, may take place afterwards.

Summary.

1. To determine the percentage hatch of *Calandra granaria* eggs, the grain containing them should be kept for 6-10 days at 25°C. after a two-day oviposition period.

2. Pretreatment of grain with mercury vapour makes no difference to the fertility of eggs afterwards laid in it.

3. At 25°C. 99 per cent. of the eggs are sterilised in 24 hours and 87 per cent. in 8 hours, using what probably approaches the saturated vapour.

4. At 10°C., the sterilisation for periods of 24, 48, and 72 hours is 44, 87 and 93 per cent. respectively.

5. At 25°C., mercury vapour will penetrate at least 30 cm. of grain in 2 days. At 12°C., mercury vapour will penetrate at least 90 cm. of grain in 7 days.

Reference.

WRIGHT, D. W. (1944). Mercury as a control for stored grain pests.—Bull. ent. Res., **35**, pp. 143-160, 1 fig.

THE DEVELOPMENT OF ARTIFICIALLY INTRODUCED INFESTATIONS OF *APHIDIUS GRANARIUS*, MARSH., UNDER FIELD CONDITIONS.

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Introduction.

It has been found to be expedient to determine the development of the Braconid parasite, *Aphidius granarius*, Marsh., under field conditions, following its artificial introduction in order to supplement the previous observations of the writer (Arthur 1944, 1945). The aim of the present work was to determine the degree of control likely to be achieved by the introduction of this parasite to corn crops known to harbour heavy Aphid infestations but lacking the corresponding parasitism. The work was undertaken during 1943-44 at Margam, Cowbridge, and Ammanford, three widely separated localities in the South Wales Area.

In all fields under consideration, the predominant Aphid pest was *Myzus festucae*, Theo., supported by varying populations of *Macrosiphum granarium*, Kirby, and *Aphis avenae*, F. Parasitism of the latter species by *Aphidius granarius* has also been noted by Skripchinskiĭ (1930) in Russia. It has been shown (Arthur, 1945) that the apterous forms of *Macrosiphum granarium*, *Aphis avenae* and *Myzus festucae*, Theo., are all subject to the attacks of *A. granarius* and *A. avenae*, Hal., under conditions of natural infestation, and that the greatest intensity of parasitic development is from April-June, thereafter declining rapidly. Some measure of control is necessary in the early part of the year, when the plant tissue is young and succulent and Aphid attack is most prevalent. Investigations were commenced in March and continued until the end of June, when Aphid damage is considerably less serious.

In South Africa, Ullyett (1938) has found hyperparasitism of the genus *Aphidius* to be general, where the Cynipid, *Charips* spp., may towards the end of the summer achieve a parasitism of some 80 per cent. of the larvae. Pteromalids may also be responsible for a further high parasitism of larvae and sometimes may even attack *Aphidius* larvae previously parasitised by *Charips* spp. On the contrary, during the period of active Aphid attack (March-July) in South Wales the dissection of large numbers of larvae of *A. granarius* showed them to be relatively immune to hyperparasitism.

Materials and Methods.

For experimental purposes fifteen fields were each sub-divided into three equal parts, such divisions being made across the width of the field, each division being represented by the numerals i, ii and iii and referred to hereafter as zones (fig. 1). The method adopted enabled the relative efficiency of the introduced parasites to be determined in different parts of the same field.

The parasite was introduced by placing ten known fertilised females of *A. granarius* in a fine muslin gauze cage, two feet long, one foot wide and one foot high, supported by a wooden framework. The base of the cage was open, so that it could be applied to the surface of the soil and enclose an area of two square feet with the Aphid-infested plants thereon. Nine such cages were arranged in diverse patterns in the field, with the object of finding the cage distribution most likely to yield maximum effectiveness over one unit area. The various arrangements of the cages are depicted in fig 1, Series A-E.

The cages were left in position for 23 to 25 days before being taken up, after first removing any adult Braconids or Aphids found crawling on the inside of the muslin cover. In order to determine the percentage parasitism in each zone of the field, 40 points were selected at random in a zig-zag pattern in each third of the field, and at each point 20 plants were removed into stout paper containers, the ends of which were closed with adhesive tape. Counts of any parasites in the field were made to trace any source of natural infestation before the cages were taken up. In one instance only was it considered desirable to treat the results with reserve. Subsequent counts were undertaken at 21 to 30 day intervals from mid March to the end of June.

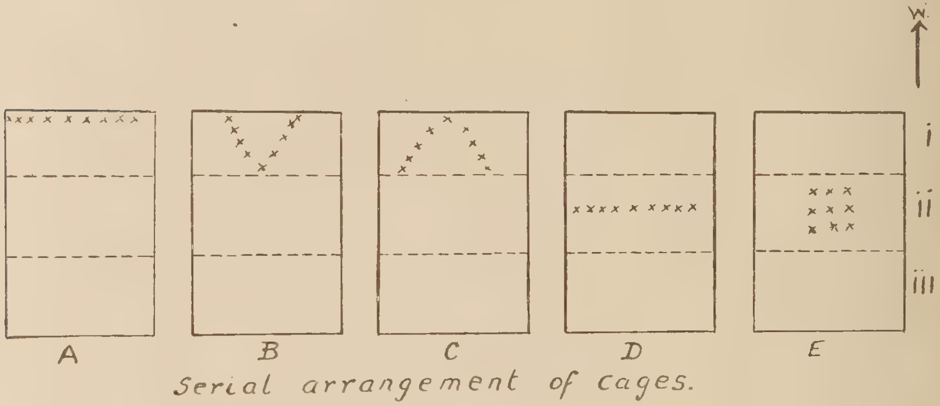

FIG. 1.—The alternative arrangements of the breeding cages employed in field experiments (Schematic).

Results.

One of the fields selected at Graig Goch, Margam, with the breeding cages ordered as in Series B, developed a natural parasite infestation in early March, the source of which was traced to the hedgerow bordering zone iii. These results are not embodied in the present discussion.

Fields with Sages arranged as in Series A.

Centres.—Garnswllt, Ammanford, Carmarthen. Graig Goch, Margam, Glamorgan. Llansannor Court, Cowbridge, Glamorgan.

The artificial populations in these fields developed from the initial figures of 543, 327 and 946 parasitised Aphids, respectively, in the second week of March; by the first week of April, an increase of 12 to 15 per cent. was recorded within a minimum and maximum range of 323 and 540 yards from the site of breeding. An examination of the zones ii and iii gave a range of parasitic influence from 3 to 5 per cent. By mid-May the populations had achieved a 40 to 65 per cent. increase within the limits of 510 and 728 yards respectively. Beyond the limits of zone i, the number of parasitised Aphids remained low and in no case did it exceed 10 per cent. In June the percentage parasitism continued to rise and in the last week of the month 67 to 83 per cent. of the Aphids were either sessile or moribund, but this concentration was still confined within the boundaries of zone i. The calculated arithmetical means of the percentage of parasitised Aphids in all three zones is presented in fig. 2, A. It is of interest to note that Aphids feeding on corn impinging on the headlands were rarely parasitised and for this reason all counts were carried out at least 15 yards from the boundary hedges.

Fields with Cages arranged as in Series B.

Centres.—Parcyrhun Farm, Ammanford, Carmarthen. Village Farm, Cowbridge, Glamorgan.

In these two fields, 264 and 965 parasitised Aphids were counted in the cages in the second week of March. The percentage increase in parasitism compared favourably with that observed in the cages of Series A, being 9 to 16 per cent. in the first April count, with the range of activity into zone ii slightly more marked. Parasitised Aphids in zone iii, however, remained a negligible quantity. During the second and third weeks of May the incidence of parasitism had risen to 50 to 55 per cent. with the main centre of activity still confined to zone i. A continued steady rise of parasitism was apparent until the last week of June, when the means of parasitic activity in zones i, ii and iii were 82, 12 and 2 per cent., respectively (fig 2, B).

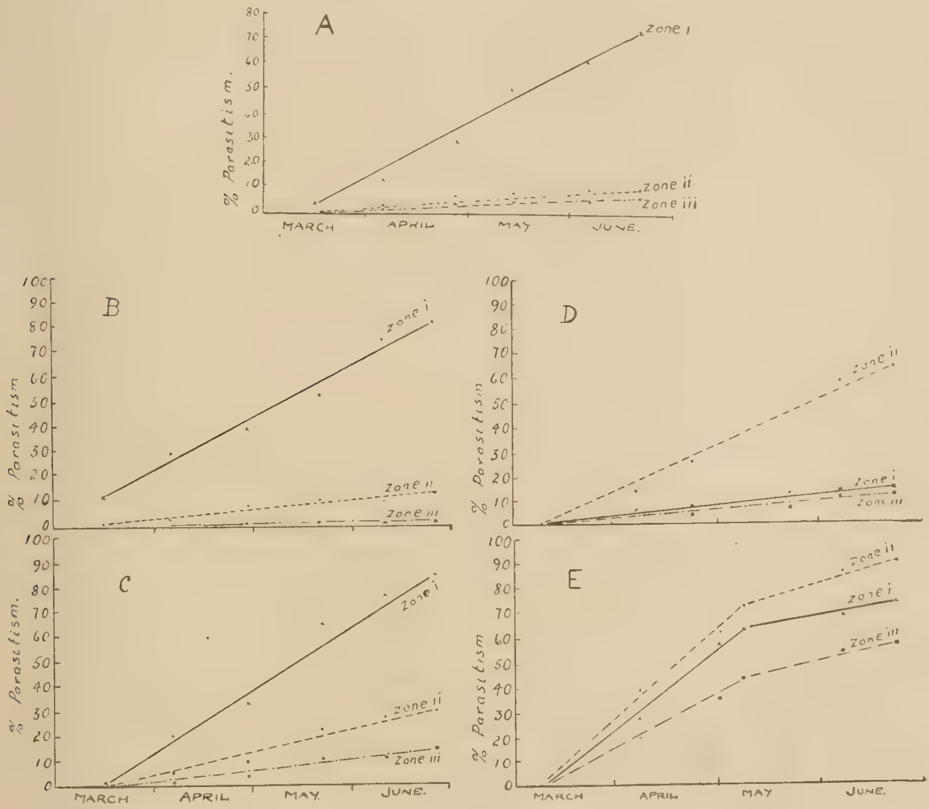

FIG. 2.—The degree of parasitism of corn Aphids by *Aphidius granarius*, when breeding cages are arranged as in fig. 1.

Fields with Cages arranged as in Series C.

Centres.—Graig Goch, Margam, Glamorgan. Wernddu, Ammanford, Carmarthen. Llansannor Farm, Cowbridge, Glamorgan.

The arrangement of the cages in these fields was the reverse of that indicated in Series B. An initial parasitism far in excess of that noted in the two previous series was observed at these three experimental areas, even in the preliminary stages of the second week of March, when 987, 1,026 and 1,112 sessile and moribund Aphids were counted. During the third week of May, an effective control of some 60 per cent. of the Aphids in zone i had been accomplished, with zone ii showing an increased control relative to Series A and B. The zone iii having some 9, 12 and 9 per cent. of the Aphids parasitised at this stage. In the last week in June the percentage parasitism ranged from 69 to 90 per cent. control in zone i, with zones ii and iii showing average figures of 30 and 15 per cent. effectiveness. The information derived from Series B and C are indicated in fig. 2.

Fields with Cages arranged as in Series D.

Centres.—Garnswllt, Ammanford, Carmarthen. Eglwys Nunydd, Margam, Glamorgan. Pencoed Uchaf, Cowbridge, Glamorgan.

In this series the cages were arranged in a linear row in the centre of zône ii. The maximum and minimum numbers of parasitised Aphids were 323 and 682 in the second week of March, increasing by 7 to 17 per cent. in the first week of April, this increase being confined within the limits of zone ii. Zones i and iii were practically devoid of any parasitised Aphids at this period. During mid-May the incidence of parasitised Aphids increased to 45 to 60 per cent. in zone ii, and fluctuated between 7 and 10 per cent. in zones i and iii. In June the figures obtained for each field in the three centres were 63, 65 and 61 per cent. (zone ii), 15, 13 and 17 per cent. (zone i), and 11, 17 and 9 per cent. (zone iii). The calculated means for each zone are given in the graph (fig. 2, D).

Fields with Cages arranged as in Series E.

Centres.—Parcyrhun Farm, Ammanford, Carmarthen. Llansannor Farm, Cowbridge, Glamorgan. Morfa Bach, Margam, Glamorgan.

By placing the cages in the centre of the field, in zone ii, in block formation, the intensity of parasitism is considerably augmented. During the second week of May the percentage parasitism in all three fields was in the vicinity of 73 in zone ii, with deviations of +5 and −7 per cent. In the adjacent zones of i and iii there was a decline of 12 and 29 per cent. from the standard mean of zone ii. By the end of June the numbers of sessile and moribund Aphids comprised some 90 per cent. of the total populations in the mid zone and 74 and 57 per cent. of the Aphids in zone i and iii respectively (fig. 2, E).

Discussion.

It will be noticed from the above experiments that the Braconid parasite, *Aphidius granarius*, can be successfully established by artificial introduction in cornfields, where the latter are heavily infested and without adequate means of natural control. The writer (Arthur, 1944) and Vevai (1942) have previously noted that alate forms of the Aphid are less susceptible to parasitism than are the apterae and the dispersal of the immature parasite stages by this means, even within the limits of a localised unit, must necessarily be considered as minimal. It has further been observed that, in nature, Aphids of the first and second instars are but rarely selected for oviposition by the parasite. Mature, but parasitised apterae, due to their mode of locomotion are likewise limited in their ability to disperse the immature parasite.

Under the conditions of experiment of Series A to D there is a very marked tendency for the concentration of the parasitised Aphids to be localised in the zones in which the initial liberation took place. Thus in zone i (Series A to C) a relatively good measure of control is apparent, whilst in zones ii and iii an efficiency of less than 30 per cent. is recorded. Similarly in Series D, where the central area (Zone ii) was subject to the original infestation, the adjacent zones (i and iii) had less than one-fourth the efficiency of the mid zone. The most satisfactory results were obtained by placing the breeding cages in the form of a block in the centre of the field, when the degree of variation on either side deviated from the mean for the whole field by -0.4 (zone i) and by -16.6 (zone iii).

It would appear that the only method of inducing the parasite to produce the desired effect on the host by artificial introduction will depend on the management of breeding cages from which initial flights of *A. granarius* take place. From the foregoing series of demonstrations, it would seem that this is most effectively carried out by concentrating the cages in the middle of the field. This bears a direct relation to the meteorological conditions which govern the flight periods of the adult parasite, as this portion of the field will automatically receive the greatest intensity of heat for the longest period of the day and will also have a minimum of shade condition. Further the location of the cages will provide a ready nucleus from which divergence in all directions, without restrictive barriers such as hedgerows, will be possible.

References.

ARTHUR, D. R. (1944). *Aphidius granarius,* Marsh., in relation to its control of *Myzus kaltenbachi* Schout.—Bull. ent. Res., **35,** pp. 257-270.

—— (1945). A note on two Braconids (Hym.) in their control of Corn Aphides (Hem.).—Ent. mon. Mag., **81,** pp. 43-45.

SKRIPCHINSKIĬ, G. (1930). Zur Biologie von *Aphidius granarius* Marsh. und *Ephedrus plagiator* Nees (Braconidae) Parasiten von *Aphis padi* L.—[*In Russian with a German summary.*]—Rep. appl. Ent., Leningrad, **4,** pp. 351-364.

ULLYETT, G. C. (1938). The species of *Aphidius* (Aphidiinae: Braconidae) as parasites of Aphides in South Africa.—Sci. Bull. Dep. Agric. S. Afr., no. 178.

VEVAI, E. J. (1942). On the bionomics of *Aphidius matricariae* Hal., a Braconid parasite of *Myzus persicae* Sulz.—Parasitology, **34,** pp. 141-151.

THE MOSQUITOES OF BWAMBA COUNTY, UGANDA.

III.—THE VERTICAL DISTRIBUTION OF MOSQUITOES IN A BANANA PLANTATION AND THE BITING CYCLE OF *AËDES (STEGOMYIA) SIMPSONI,* THEO.

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In 1941 yellow fever virus was isolated from a human patient and from wild-caught mosquitoes—*Aëdes* (*Stegomyia*) *simpsoni,* Theo.—in Bwamba County, Western Province, Uganda. An intensive entomological study of the area was begun early in 1942 and is still in progress. Bwamba is a small county in the extreme west of Uganda, lying between the Ruwenzori Mountains and the Semliki River. The topography and vegetation of the county have been described in an earlier communication (Haddow, 1945,a).

It has been established that *A. simpsoni* is the vector involved in human outbreaks of yellow fever in Bwamba. The epidemiology, however, involves the persistence of endemic yellow fever, transmitted by sylvan mosquitoes, among the animals of the Semliki Forest. Evidence of this animal-to-animal cycle is shown in the fact that over 60 per cent. of Bwamba monkeys are immune to yellow fever, and final proof was given by the recent isolation of virulent virus from forest *Aëdes* (not including *A. simpsoni* or *A. aegypti*) captured in uninhabited virgin rain-forest.

Previous work (Haddow, 1945,b) has shown that *A. simpsoni* is strictly diurnal, prefers human blood, and attacks the head and shoulders selectively. It is the dominant species in banana plantations, from which it diffuses into adjacent coffee gardens and maize fields. In banana plantations it is most prevalent in the thinner parts where young plants predominate, and round the edges. Though common in tree holes in West Africa (Dunn, 1926), larvae in Bwamba are almost entirely restricted to plant axils—mainly those of *Colocasia,* pineapple, and one variety of banana. *A. simpsoni* does not enter houses and penetrates only the extreme edges of the rain-forest. Many sylvan mosquitoes, on the other hand, leave their normal habitat by night and diffuse into banana plantations.

The series of catches here reported was made to investigate in further detail the biting habits of *A. simpsoni* and to obtain additional evidence of the activity of forest mosquitoes in banana plantations.

One way in which yellow fever could be conveyed from forest animals to inhabited areas might be through the presence of an infected animal among a band of monkeys robbing a plantation, with subsequent infection of *A. simpsoni.* It was therefore considered important to establish whether or not this mosquito showed biting activity above ground level, and particularly among the leaves and banana clusters of the larger plants.

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* This Institute is supported jointly by the Medical Department of the Uganda Protectorate and the International Health Division of The Rockefeller Foundation.

Methods.

In the area selected for investigation (Bubukwanga) there is a large banana plantation, almost a square mile in extent. The distance from the edge of this plantation to the nearest forest is about half a mile. Three wooden platforms, each 6 ft. square, were built side-by-side near the edge of the plantation. The highest, at 18 ft., was clear above the tops of the largest plants, in the open air. The next, at 12 ft., was among the leaves of the full-grown plants. The last, at 6 ft., was among the leaves of the young bananas, but well above the low undergrowth. A fourth station was chosen on the ground beside the 6-foot platform. This last was among fairly heavy undergrowth, here mainly *Colocasia* and grasses.

Previous work in Bwamba has shown that the most effective method of gaining information about the biting habits of mosquitoes is to make continuous catches of 24 hours each, using human bait. The present series consisted of 10 such catches, made simultaneously at all 4 levels, each hour's catch from each level being recorded separately. The unit at each station consisted of 4 small African boys. Five units were employed, 4 working and 1 resting. At each clock-hour the unit which had rested moved up to the top platform, the other units each moved down 1 platform, and the ground-level group went off to rest. This gave working-spells of 4 hours, divided by 1-hour rest periods. Each catch began at 06 hours (local mean time) and ended at the same time on the following morning. Food and tea were issued in liberal quantities and overtime pay was also given. Two senior boys worked turn about in 3-hour spells as superintendents. The work was kept under close personal supervision by the writer, particularly at night. Such supervision is considered absolutely essential if the results are to be regarded as critical, even where the most experienced and willing African assistants are employed.

Species List.

At this point it is convenient to list the species taken, so that abbreviated names may be used in tables and discussion. The nomenclature and systematic arrangement are those of Edwards (1941).

Anopheles (*Anopheles*) *paludis,* Theo.
A. (*A.*) *implexus,* Theo.
A. (*Myzomyia*) *funestus,* Giles
A. (*M.*) *gambiae,* Giles
A. (*M.*) *pharoensis,* Theo.
Taeniorhynchus (*Coquillettidia*) *fuscopennatus,* Theo.
T. (*C.*) *aurites,* Theo.
T. (*Mansonioides*) *africanus,* Theo.
T. (*M.*) *uniformis,* Theo.
Aëdes (*Stegomyia*) *simpsoni,* Theo.
A. (*S.*) *apicoargenteus,* Theo.
A. (*S.*) *africanus,* Theo.
A. (*Aëdimorphus*) *cumminsi,* Theo.
A. (*Banksinella*) *circumluteolus,* Theo.
Eretmapodites chrysogaster, Graham
Culex spp. indet.

TABLE I.

Vertical Distribution of Mosquitoes. Total Figures for all Species.

Species	Ground	6 feet	12 feet	18 feet	Total
Anopheles paludis	—	1	—	—	*1*
A. implexus	—	1	—	—	*1*
A. funestus	1	—	—	—	*1*
A. gambiae	1	—	2	—	*3*
A. pharoensis	2	—	2	1	*5*
Taeniorhynchus fuscopennatus ...	—	1	—	—	*1*
T. aurites	—	1	—	—	*1*
T. africanus	17	14	14	1	*46*
T. uniformis	2	3	4	5	*14*
Aëdes simpsoni	179	159	141	117	*596*
A. apicoargenteus	—	—	—	1	*1*
A. africanus	2	—	1	—	*3*
A. cumminsi	2	—	—	—	*2*
A. circumluteolus	1	—	—	—	*1*
Eretmapodites chrysogaster	2	1	—	—	*3*
Culex spp. indet.	1	1	3	3	*8*
Totals	*210*	*182*	*167*	*128*	*687*
Number of species and groups ...	*11*	*9*	*7*	*6*	*16*

Vertical Distribution of Mosquitoes.

The figures with regard to vertical distribution are set forth in Table I. It is regrettable that *A. simpsoni* was the only really abundant species. Among the others *T. africanus* alone is worthy of discussion. The scarcity of this species at 18 ft., contrasted with its relative abundance up to 12 ft., can hardly be explained in terms of microclimate as, at night, when this mosquito reaches its maximum activity, the climate of a banana plantation and the open air are almost identical (Haddow, 1945,a). It seems that *T. africanus* may prefer to bite under shelter, and this may be in accordance with its habits of entering huts and tents in large numbers just after dark.

It is worth noting that mosquitoes of 6 species of a total species list of 16 were taken biting on the highest platform.

It was most interesting to find *A. simpsoni* prevalent at all altitudes, though the abundance decreased with increasing height. As almost 25 per cent. of the total were caught at 12 ft., among the large leaves and banana bunches, there seems little doubt that an infected monkey feeding at this height could easily pass on yellow fever virus to *A. simpsoni*. The prinicipal raiding monkey in Bwamba is *Cercopithecus nictitans mpangae,* Matschie, the common red-tail or white-nosed guenon. It is known that yellow fever is prevalent in this species, as 25 (61 per cent.) of a total of 41 Bwamba red-tails have been found to be immune to the disease.

Notes on Species other than A. simpsoni.

The presence of forest mosquitoes such as *A. implexus, A. apicoargenteus,* and *A. africanus,* though in small numbers, is of interest in connection with the diffusion of sylvan species into plantations. The nearest breeding-places of *A. apicoargenteus* and *A. africanus* were in the forest about half a mile away, where larvae were abundant in tree holes. It may also be noted that in Bwamba (though not in all parts of their geographical range) *A. paludis, T. fuscopennatus,* and *A. cumminsi* are essentially forest species.

Unfortunately, almost all species except *A. simpsoni* were scarce and their numbers are inadequate for discussion of the biting-cycle. In the case of the more abundant, such as *T. africanus* and *T. uniformis*, the results are in agreement with those obtained in previous and more extensive catches (Haddow, 1945,b).

It is interesting to note that while only 3 species were present by day, 13 were taken by night. The species taken by day were *T. africanus, A. apicoargenteus,* and *E. chrysogaster,* while those taken by night were *A. paludis, A. implexus, A. funestus, A. gambiae, A. pharoensis, T. fuscopennatus, T. aurites, T. africanus, T. uniformis, A. africanus, A. cumminsi, A. circumluteolus,* and *Culex* spp. As in previous work the 4-hour period following sunset (18-22 hours) was the most productive, both from the point of view of numbers captured and of variety of species. In the present series this period yielded 11 species (*A. paludis, A gambiae, A. pharoensis, T. fuscopennatus, T. aurites, T. africanus, T. uniformis, A. africanus, A. cumminsi, A. circumluteolus,* and *Culex* spp.). It seems likely that the importance of this period after sunset may be due to the fact that it is the only time when fairly high temperatures occur in conjunction with very high atmospheric humidity. In general, the most productive part of the period is the first hour after sunset (18-19 hours), and it is possible that here suitable low light intensities may play a part.

It will be noted that in this section the mixed group of *Culex* spp. has been counted, for convenience, as a single species. The group consisted of the almost unidentifiable females of the subgenus *Culiciomyia,* with 1 or 2 small *Culex* s. str., near *C.* (*C.*) *univittatus,* Theo.

The Biting Cycle of A. simpsoni.

During previous work in Bwamba it was found best to discuss the biting cycle of mosquitoes by 4-hour periods, starting at 06 hours (Haddow, 1945,b). The obvious reason why such a grouping should be the most useful for general purposes is that it accords well with the successive climatic phases of the day. In connection with the strictly diurnal *A. simpsoni* the night periods need not be discussed, but it may be worth noting that the day periods have the following characteristics:

1. 06-10 hours. Temperature and saturation deficiency very low, relative humidity high.

2. 10-14 hours. Temperature and saturation deficiency at their maximum, relative humidity at its minimum.

3. 14-18 hours. Temperature still high, but saturation deficiency rapidly falling and relative humidity rapidly rising.

Considering the biting curve of *A. simpsoni* by these periods (Table II and fig. 1), it is found that at ground level and at 6 ft. activity increases throughout the day with a maximum in the third period (14-18 hours). The most favoured period is thus one whose main characteristics are warmth and high humidity.

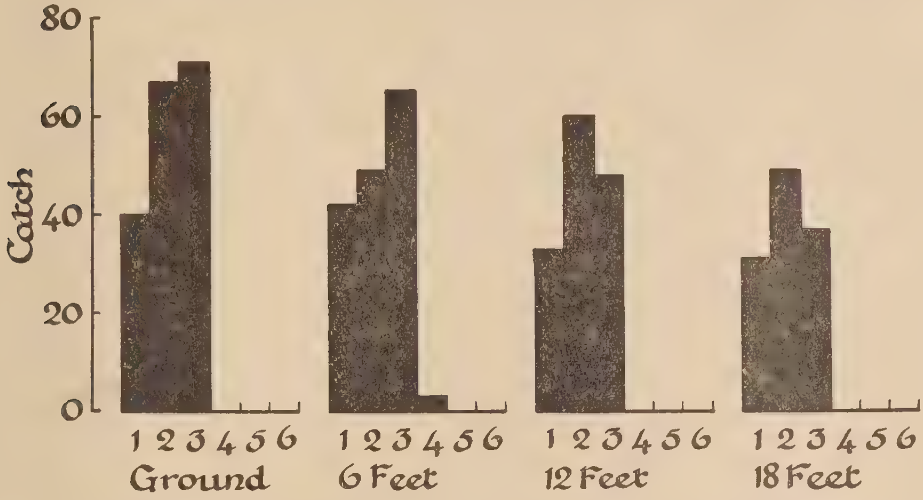

FIG. 1.—The biting cycle of *A. simpsoni* at different levels (4-hour grouping). The numbers below the histograms represent the successive periods, namely: *1.* 06–10 hours. *2.* 10–14 hours. *3.* 14–18 hours. *4.* 18–22 hours. *5.* 22–02 hours. *6.* 02–06 hours.

At 12 and 18 ft. the most marked activity occurs during the midday period (10-14 hours), the afternoon level being much lower. The explanation of this decrease in numbers during the afternoon is that in Bwamba a breeze blows daily from the mountains at this time. This breeze, while affecting biting at the fairly exposed 12 foot and completely exposed 18 foot levels, is rarely strong enough to have any influence on activity in the shelter of the bananas, young plants and undergrowth at ground level and 6 ft.

TABLE II.

The biting Cycle of *A. simpsoni* at different Levels
4-hour Grouping

Level	06–10	10–14	14–18	18–22	22–02	02–06	Total
Ground	40	68	71	—	—	—	179
6 feet	42	49	65	3	—	—	159
12 feet	33	60	48	—	—	—	141
18 feet	31	49	37	—	—	—	117
All levels	*146*	*226*	*221*	*3*	—	—	*596*

Previous work in Bwamba by Gibbins (1942) and the writer (1945,b) showed *A. simpsoni* to be most active in the morning and late afternoon. This characteristic is not apparent in the 4-hourly figures, but is clearly shown if the hourly catch is considered (Table III and fig. 2). It is apparent from fig. 2 that there are no really marked peaks; it would be more correct to infer a high level of activity throughout the daylight hours, partly inhibited during the hottest and driest period from 13-14 hours. This suggestion is supported by the fact that on cloudy humid days *A. simpsoni* sometimes bites almost uniformly from sunrise to sunset.

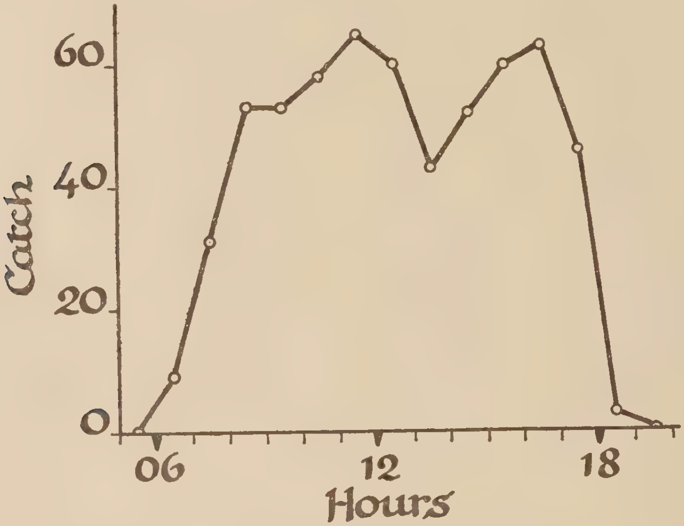

FIG. 2.—The biting cycle of *A. simpsoni*, combined figures for all levels, by 1-hour groups. Night hours are not shown, as no *A. simpsoni* were taken after 19–20 hours.

It so happened that the period of the 10 catches consisted of 5 days each of 2 different types of weather. In the first type a clear chilly period after sunrise was succeeded by a bright hot day. In the second, a rather warm, close morning period was followed by an overcast day, warm but not hot and lacking bright sunshine. Both Gibbins (1942) and the writer (1945,b) have previously noted that the second type of weather is preferred by *A. simpsoni*, and the present figures support this observation (Table III and fig. 3). Fig. 3 shows clearly that on the overcast days with warm morning *A. simpsoni* bit in large numbers, becoming active almost immediately after sunrise at 06 hours, while on the hot, bright days the catch was much smaller and activity was inhibited during the cold, early morning, no mosquitoes being taken till 08-09 hours.

TABLE III.

The biting Cycle of *A. simpsoni*, 1-hour Grouping.

(The night hours are omitted, as no *A. simpsoni* were caught later than 18–19 hours.)

Hour	*06–07*	*07–08*	*08–09*	*09–10*	*10–11*	*11–12*	*12–13*	*13–14*	*14–15*	*15–16*	*16–17*	*17–18*	*18–19*	*Total*
5 hot bright days, with cold morning	—	—	9	12	15	20	16	12	17	16	16	18	—	*151*
5 warm cloudy days, with warm morning... ...	9	31	44	41	43	45	44	31	35	44	47	28	3	*445*
Total results of all 10 catches	9	31	53	53	58	65	60	43	52	60	63	46	3	*596*

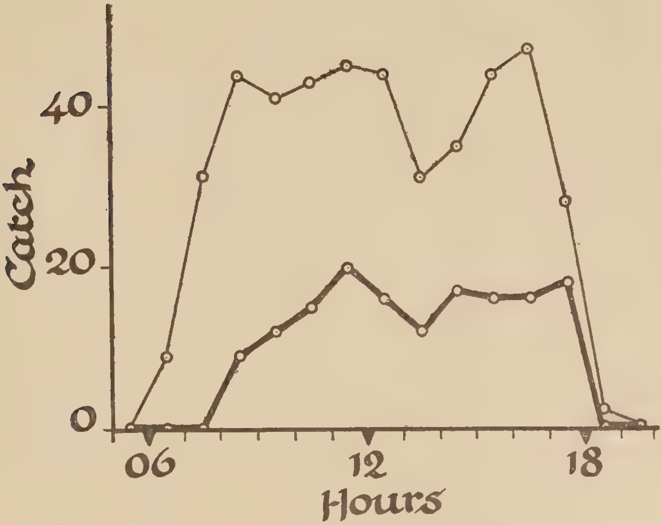

FIG. 3.—The biting cycle of *A. simpsoni*, combined figures for all levels, by 1-hour groups *Thick line* = results for 5 hot bright days with cold morning. *Thin line* = results for 5 warm cloudy days with warm morning. Night hours are not shown as no *A. simpsoni* were taken after 19–20 hours.

It thus appears that in general *A. simpsoni* prefers warm, cloudy weather, and that the main influences reducing biting activity are wind, cold, and direct hot sunshine.

Summary.

1. The work here reported was carried out in Bwamba County, Uganda, a district where human yellow fever has recently occurred. It consisted of continuous 24-hour catches of biting mosquitoes in a banana plantation, made simultaneously at ground level, 6 ft., 12 ft. and 18 ft.

2. *Aëdes* (*Stegomyia*) *simpsoni,* Theo., the carrier of human yellow fever in Bwamba, was found to be active throughout the day at all these levels.

3. The presence of sylvan mosquitoes in the banana plantation was noted. The nearest forest was ½ mile away.

4. The biting cycle of the strictly diurnal *A. simpsoni* was studied, and it was found that this species was most active on warm cloudy days. The main factors decreasing its activity appeared to be cold, wind, and direct hot sunshine.

References.

DUNN, L. H. (1926). Mosquitoes bred from dry material taken from holes in trees.—Bull. ent. Res., **17,** pp. 183-187.

EDWARDS, F. W. (1941). Mosquitoes of the Ethiopian Region. III. Culicine adults and pupae.—London, Brit. Mus. (Nat. Hist.).

GIBBINS, E. G. (1942). On the habits and breeding-places of *Aëdes* (*Stegomyia*) *simpsoni* Theobald in Uganda.—Ann. trop. Med. Parasit., **36,** pp. 151-160.

HADDOW, A. J. (1945,a). On the mosquitoes of Bwamba County, Uganda. I. Description of Bwamba with special reference to mosquito ecology.—Proc. zool. Soc. London, **115,** pp. 1-13.

——. (1945,b). The mosquitoes of Bwamba County, Uganda. II. Biting activity with special reference to the influence of microclimate. Bull. ent. Res., **36,** pp. 33-73.

THE IDENTITY OF A MEALYBUG VECTOR OF "SWOLLEN SHOOT" VIRUS DISEASE OF CACAO IN WEST AFRICA.

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A new mealybug injurious to cacao in the Gold Coast was described by Laing in 1944 under the name of *Pseudococcus exitiabilis* (Bull. ent. Res., **35**, p. 91). It was said that it had been reported by the collector, Mr. H. E. Box, to be one of the Coccid vectors of the "swollen shoot" virus disease of cacao. This was later confirmed by Box (Nature, **155**, 1945, p. 608).

The future of the cacao industry in the Gold Coast is seriously threatened by the "swollen shoot" outbreaks and consequently intensive collecting was at once undertaken to ascertain the distribution of *P. exitiabilis* and to establish what, if any, other host plants it attacked. The writer has been impressed by the initiative shown by Mr. Box in his approach to the whole problem. Credit is also due to him as well as to Messrs. A. H. Strickland*, D. Westwood and others for the large amounts of Coccid material they have collected and dispatched to the Imperial Institute of Entomology. Many interesting species are represented, including at least seven new records of Coccids attacking cacao in Africa. It is proposed to deal with these separately and to confine the present paper to a discussion of the 80 lots of mealybug material which were suspected to be *exitiabilis*.

The study of this extensive range of material has made it clear that the species is one of very considerable variation, and it is still by no means clear what the limits may prove to be. One of the very first lots of material examined differed so widely from typical *exitiabilis* that it might well have been considered a distinct species, but later intermediate forms came to hand which furnished a chain of links between the two so that at no point was it possible to draw a line of demarcation. Several of the characters show variation, even in the individuals from the same lot, but in all cases a series of specimens could be selected showing gradation from one extreme to the other. Moreover, in those cases in which material appeared to differ from typical *exitiabilis* in more than one character, the same combination of differing characters was not found to exist in other lots of material. There is no evidence of any particular form being peculiar to any particular locality or to any particular host plant except in the cases of *Ceiba pentandra* and *Canthium glabriflorum* to which reference will be made later.

In describing *exitiabilis*, Laing pointed out that it is so close to *Pseudococcus njalensis*, described from Sierra Leone on coffee (Ann. Mag. nat. Hist., (10) **4**, 1929, p. 472), that "further experience of the two species may result in their union" the points of difference between the two being said to be comparative. In the opinion of the writer, based on the evidence discussed fully below, Laing was correct in his surmise and the two species should be united under the prior name of *P. njalensis*.

The types of both *njalensis* and *exitiabilis* have been available for examination. Apart from the differences drawn attention to by Laing, there is one point of similarity that is here considered to be of considerable importance. On the mid dorsal dermis the segments carry elongate irregularly oval groups of small circular

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* Mr. Strickland in particular is to be congratulated on the large amount of interesting material that he has collected.

disc pores; these do not extend posterior of the anterior abdominal segments, and towards the frontal region they become fewer and scattered. A few similar but scattered pores are found on the dorsal dermis in the vicinity of the margin. The general arrangement can be seen from the figure which was drawn from a young

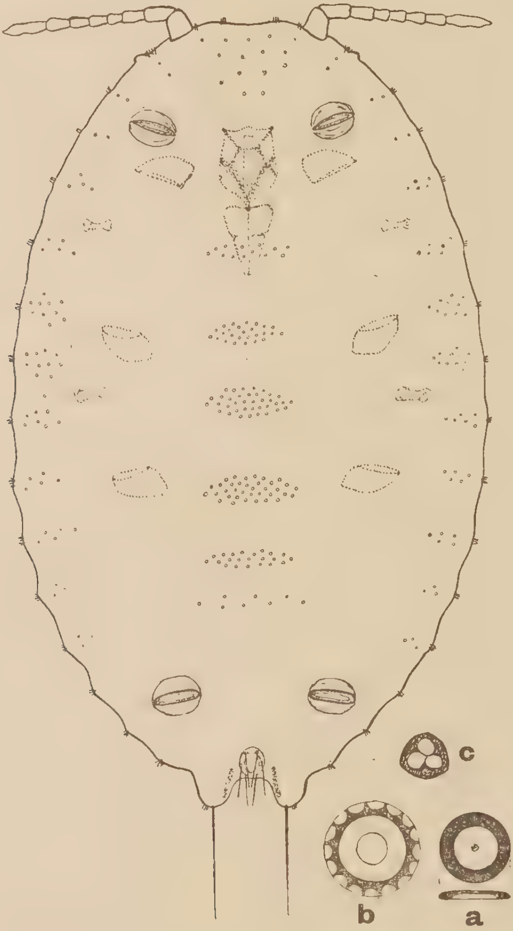

FIG. 1.—Young adult ♀ from cacao—dorsal dermis showing arrangement of dermal disc pores; A, B and C. Dorsal disc pore, multilocular pore from ventral aspect of the posterior abdominal segments and trilocular pore, respectively, all drawn to the same scale.

adult female; in the fully-developed adult female the pores in the mid dorsal groups are not so closely set.

The structure of the pores is obscure. They are flat and disc-like, circular, with a sclerotised rim; the central portion is not divided up into loculi, but there is a darkish central spot.

The pores are remarkably constant in size and are slightly smaller in diameter than the multilocular disc pores on the ventral aspect of the posterior abdominal segments (3:4). No other species is known in which such an arrangement of similar pores occurs. Although some variation is found in the number present, particularly in the marginal region, they were found to occur in every individual prepared from the 80 lots of material here recorded, irrespective of the variation in other characters.

It was thought at first that these pores represented sockets from which setae had become displaced, but the setae are of varying sizes with sockets of correspondingly dissimilar sizes, whereas the pores are remarkably uniform in size. In view of the hundreds of individuals prepared, one would hardly expect the same groups of setae always to become dislodged; moreover they are most clearly visible in the earliest adult females in which, moulting having only recently taken place, one would expect to find the setae still in place. In two pre-adult females within which the adult females were clearly discernible the pores could be distinctly seen. Sockets from which setae have become dislodged have a more densely sclerotised rim.

In the pre-adult or nymphal females the pores are also present but are much fewer in number.

In describing *exitiabilis*, Laing recorded its close relationship not only with his *njalensis* but also with *P. hispidus*, Morr., from Malaya and *P. jacobsoni*, Green, from Sumatra. Judging from the descriptions of the two latter species, this is certainly the case, but specimens received from Malaya on cacao which are believed by the writer to be *hispidus* show no signs of the dorsal dermal pores so characteristic of *njalensis* and *exitiabilis*. The presence of these pores is not a feature of the genus *Pseudococcus*, and whether *njalensis* can be correctly assigned to that genus will require a more extended study of allied species and genera.

The following is a list of the material that has been examined:

Samydaceae.

Homalium sp.—SIERRA LEONE: Njala, 4.xi.32 (*E. Hargreaves*, No. 544).

Ochnaceae.

Lophira alata—GOLD COAST: nr. Ejura, Ashanti (H. 1415).

Lecythidaceae.

Napoleona vogelii—GOLD COAST: Koransang (H. 5144).

Sterculiaceae.

Cola togoensis—GOLD COAST: nr. Wenchi, Ashanti (H. 1413).

Octolobus spectabilis—GOLD COAST: Akrum Falls (H. 1149).

Sterculia rhinopetala—GOLD COAST: Bunsu (H. 1424).

Sterculia setigera (*tomentosa*)—GOLD COAST: nr. Wenchi, Ashanti (H. 1361); FRENCH TOGOLAND: nr. Lome (H. 1192).

Theobroma cacao (Cacao; introduced)—SIERRA LEONE: Kwaoma, 21.i.40 (*F. A. Squire*); IVORY COAST: Abengouron (*H. Alibert*, H. 1367); GOLD COAST: Ashanti, Tepa (H. 1353); Kunsu (H. 1351); Central Prov.: Bawdua (H. 1411); Koransang (H. 5148); Eastern Prov.: Tafo (H. 253; three separate collections, in addition to the type series of *exitiabilis*); Kwahu (H. 1404); Nkawkaw (H. 1405, 5117, 5118, 5122, 5124); Abetima

(H. 5008, 5009); Bunsu (H. 5091); Suhum (H. 5142, 5146, 5147); Osino (H. 5153); Kobriso (H. 5156 to 5162); Afram Plains—various localities—(H. 5056, 5058 to 5064, 5086, 5102, 5104, 5106 to 5112, 5163); BRITISH TOGOLAND: Bame Pass (H. 1375); Dafo (H. 1380); Flato Falls (H. 1384); FRENCH TOGOLAND: Mayondi (across frontier from Honuta) (H. 1385); NIGERIA: Ikire (Ibadan—Ife road, H. 1201).*

Bombacaceae.
Ceiba pentandra—GOLD COAST: Koransang (H. 1431).

Euphorbiaceae.
Alchornia cordifolia—GOLD COAST: Nkawkaw (H. 5119).

Leguminosae.
Delonix regia (*Poinciana regia*)—SIERRA LEONE: Njala (*E. Hargreaves*).

Moraceae.
Myrianthus arboreus—GOLD COAST: Tafo (H. 254).

Olacaceae.
Strombosia pustulata—GOLD COAST: Bunsu (H. 1425).

Sapindaceae.
Chytranthus sp.—GOLD COAST: nr. Amentia (H. 1096).
Lecaniodiscus cupanioides—NIGERIA: nr. Ilesha (H. 1253).

Apocynaceae.
Voacanga africana—GOLD COAST: Pimpinso (H. 1435).

Rubiaceae.
Canthium glabriflorum—GOLD COAST: Tafo (H. 5175); Bunsu (H. 1403, 1426); Bosuso (H. 1433, 1434); NIGERIA: Ijebu Ode (H. 1248).
Coffea excelsa (cultivated coffee)—BR. TOGOLAND: Dafo (H. 1381).
Coffea sp. (cultivated coffee)—SIERRA LEONE: Njala (type lot of *njalensis*).
Cuviera acutiflora—GOLD COAST: Asuansi (H. 1023).

Verbenaceae.
Clerodendrum sp.—GOLD COAST: Bunsu (H. 1350).

Bromeliaceae.
Ananas comosus (Pineapple, introduced)—GOLD COAST: Adenchensu (H. 5103).

Also H. 5116, 5121, on unknown host plants from Nkawkaw and another lot of material of which the particulars were lost.

All material except that from Sierra Leone collected between 1943 and 1945.

It will be seen that the material available for examination was collected not only in many localities in the Gold Coast but also in Sierra Leone, Ivory Coast, British and French Togoland and Nigeria. The host plants other than cacao are numerous and include coffee on which the original material of *njalensis* was collected; according to Mr. Box they range through primitive rain-forest to open savannah woodlands.

Attention has already been drawn to the variation observed in this extensive lot of material. More detailed remarks on this variation may now be given.

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* Mr. Box reports that this was the only material found during an extensive search covering the cacao areas of Nigeria.

Antennae.

The relative lengths of the antennal segments are comparatively constant but the overall length of the antenna shows some variation. In the type of *exitiabilis* it varies from 96 to 104,* in *njalensis* from 100 to 112, whilst in the large range of other material examined, it varies from 92 to 132. The longest form was found in specimens from Nigeria on cacao and the shortest from the Gold Coast on *Canthium*, but in the latter case the individuals varied from 92 to 112 and overlapped with those from cacao and other host plants. No satisfactory dividing line can be drawn on the basis of this character.

Hind Limbs.

The lengths of the tibia, tarsus and femur of the hind pair of limbs as well as their relative lengths show some variation.

	Tarsus	Tibia	Femur
1. *njalensis* (type and paratypes)	25–26	38–46	47–56
2. *exitiabilis* (type)	22	41	51
3. *exitiabilis* (long range of individuals on cacao from the type locality)	24–26	35–48	44–59
4. H.5009 on cacao from Gold Coast	22–23	37–38	47–48

It will be noted that a long range of specimens from cacao from the type locality, Tafo, Gold Coast, gave a range covering both the types of *njalensis* and *exitiabilis* with the exception of the tarsus which in the type specimen of the latter species was slightly shorter. A specimen on cacao from the Gold Coast, however, showed a tarsus of similar dimensions. Other specimens from the long range of material fell within the limits given under 3.

The width of the tibia and tarsus shows some variation, and in *njalensis* it tends to be greater than in *exitiabilis*. This gives the limbs in *njalensis* the appearance of being not only stouter but shorter than in *exitiabilis*. The maximum width of the hind tibia in *njalensis* varies from 11 to 15 and in the type of *exitiabilis* it is 10. The great majority of individuals range about 10 or 11 but in some the width is greater. In specimens from *Octolobus spectabilis* from the Gold Coast, the width varied between 11 and 14, and in a single specimen (No. 4 above) on cacao from the Gold Coast, one hind tibia was 10 whilst the other was 13. In the two other lots of material from Sierra Leone the width of the tibiae varied from 9 to 12 (mostly 10 or 11) and the limbs were of dimensions approximating to the type of *exitiabilis*. In specimens on coffee from British Togoland the limbs were typical of *exitiabilis*.

The translucent pores towards the distal extremity of the hind femur are variable not only in different lots of material but also in the individuals of any given lot. They vary from being entirely absent to being relatively numerous.

A study of all the material available indicates that so far as the hind limbs are concerned there are no constant differences which would enable *njalensis*, *exitiabilis* or other forms to be separated.

Cerarian Spines.

Considerable variation is found in the number of spines in the various cerarii; this variation occurs between different lots of material and also within the range of individuals from any one lot.

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* The same unit for comparative measurements has been used throughout this paper.

Each example represents two complete sets of 18 cerarii.

No. of Cerarius	*njalensis* after Laing	*exitiabilis* after Laing	*exitiabilis* from type locality		H.1201 *T. cacao*	H.1361 *Sterculia setigera*	H.5008 *T. cacao*	H.1413 *Cola togoensis*
			Range 40 ex.	Av. 37 ex.	Nigeria Av. of 5 ex.	N. Ashanti Av. of 10 ex.	Gold Coast Av. 2 ex.	Gold Coast Av. of 8 ex.
18	3	3–4	2–5	2·7	2·3	2·0	2·7	2·9
17	3	5–6	3–8	5·2	3·2	3·0	7·0	6·5
16	4	4–5	3–8	5·1	3·9	2·9	6·5	5·9
15	4	4–5	3–7	4·6	3·6	2·6	5·2	5·9
14	6	4–7	3–7	4·7	3·3	2·4	5·7	5·2
13	5	5–6	3–7	4·5	3·0	2·6	5·5	4·7
12	4	4–5	2–7	4·4	2·6	2·6	5·2	4·9
11	3	4–5	2–6	3·7	2·7	2·0	5·0	3·9
10	3	3–6	2–5	3·2	2·2	2·1	4·5	3·8
9	3	4	2–6	3·4	2·8	2·0	4·5	3·8
8	4	4–5	2–5	3·4	2·5	2·0	4·5	3·4
7	3	4–5	2–6	3·3	3·0	2·1	5·0	3·2
6	2	2–3	1–6	2·9	2·3	2·0	4·7	3·3
5	2	2–4	1–3	2·1	1·9	2·0	3·0	2·1
4	4	3–4	1–5	3·0	2·0	2·0	4·7	3·4
3	4	4–7	2–7	4·4	3·5	3·4	5·0	5·6
2	2	3	1–4	2·4	2·2	2·1	3·0	3·0
1	2	3–4	2–5	2·8	2·0	2·0	4·5	3·7

It will be seen that a series of specimens from cacao from the type locality—Tafo—had not only a wide variation but a range which covered both those of *njalensis* and *exitiabilis* as described. The smallest number of spines were found in H.1201 on cacao from Nigeria and H.1361 on *Sterculia setigera* from Ashanti, and the largest number on H.5008 on cacao from the Gold Coast and H.1413 on *Cola togoensis* from the Gold Coast. Other lots of material provided intermediate forms. It was not found possible to correlate the number of spines with either the host plant or the locality. Specimens from other lots of material from Nigeria had a more or less normal spine count as did specimens from another lot of material on *Sterculia setigera* from French Togoland (H.1192).

In *njalensis,* according to Laing, the cerarian spines tend to be longer and more slender than in *exitiabilis.* In both species the spines in any one cerarius are of dissimilar sizes, and in the range of material now to hand no significant differences can be seen.

Cerarian Pores.

The pores are not so numerous or quite so densely crowded in *njalensis* as they are in *exitiabilis.* The great majority of the specimens examined resemble *exitiabilis* rather than *njalensis* but a few approach *njalensis* and some material on *Canthium* showed a condition very similar to *njalensis.*

Dermal Setae.

It is in this character that the greatest and most striking variation is found. Comparison of one lot of material with another and of one specimen with another is complicated by the fact that the setae do not always show up equally well and some, particularly the longer setae, are apt to be missing. The appearance also varies according to the size of the individual, the setae being more closely set together and consequently more obvious in the smaller individuals than in those which are fully developed. The setae in all specimens show a very wide range in length in any one given individual. A study of all the material in hand shows that the relative lengths of the longest setae on the lips of the posterior osteoles furnish a reasonably accurate index of the relative lengths of the dermal setae. In the type of *exitiabilis* the length varies from 25-30 whilst in the long range of specimens of *exitiabilis* from the type locality the length varied from 25-35. In *njalensis* the length is relatively less, 15-25, but in specimens from *Cuviera acutiflora* from the Gold Coast (H.1023) a similar length was found. In these specimens and in *njalensis* the dermal setae are appreciably shorter than in typical *exitiabilis*. In H.1381 on *Coffea* from British Togoland the dermal setae were as found in typical *exitiabilis*. Other material provides intermediate forms between *njalensis* and *exitiabilis*, and there is some variation in the individuals in any given batch.

There is another form with definitely longer dermal setae represented by H.1201 on cacao from Nigeria (35-45), H.1350 on *Clerodendrum* from the Gold Coast (35-45) and H.1367 on " swoollen shoot " cacao from the Ivory Coast (40). Again other lots of material supply the intermediate forms between typical *exitiabilis* and this long seta form. The two extremes H.1023 on *Cuviera acutiflora* and H.1201 on cacao seen side by side look markedly different in the nature of their dermal setae yet a complete gradation from the one to the other can be seen in the material under examination.

Caudal and Anal Setae.

The actual and relative lengths of the caudal and anal setae are comparatively constant. The caudal setae are long and rather stout at the base and are about three times as long as the setae of the anal ring. The latter although so much shorter are also rather stout at the base. The relative lengths of caudal to anal setae are 85 : 26. This also applies to the specimens from *Canthium* and *Ceiba* referred to below.

Material from Canthium glabriflorum* and Ceiba pentandra.

The most puzzling aspect of the whole problem was presented by material collected on *Canthium glabriflorum*. H.5175 from Tafo from inside the hollow stems of the host plant, H.1403 from Bunsu (Gold Coast) from inside stems of young *Canthium*, and H.1433 from outside the trunk of mature *Canthium* were all more or less typical *exitiabilis*. H.1426 and H.1434, the first from Bunsu, the second from Bosuso (about one mile away), both from the inside of *Canthium*, were markedly different, so much so that the writer would have regarded them as representing a distinct species. Yet H.1433 was collected from outside and H.1434 from inside the stems of the same individual *Canthium* tree. Further H.1403 and H.5175 both from the inside colonies are typical *exitiabilis*.

H.1426 and H.1434 differ from H.1433, which is typical of *exitiabilis*, in having markedly shorter and less conspicuous dermal setae, the relative lengths of the longest setae on the posterior osteoles range from 8-10 compared to 25-35 in *exitiabilis* and 35-45 in the long seta form. Other differences are that the size is consistently smaller and the circular dorsal dermal pores particularly in the marginal region are more numerous and extend as far as the penultimate cerarii. The cerarian pores are fewer and more scattered resembling the condition found in *njalensis*. They bear a closer relationship to *njalensis* than any other form seen but the dermal setae are very much shorter. Final judgement on this form will be reserved until further material from both inside and outside *Canthium* stems is available.

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* This tree is an obligatory myrmecophyte, inhabited by ants of the genus *Crematogaster*, those from Bunsu and Bosuso having been identified by Mr. Donisthorpe as *C.* (*Atopogyne*) *cuvierae*, Donis., which also inhabits *Cuviera acutiflora* in the Gold Coast. In young *Canthium* trees, up to about 6 ft. high, the ant colonies appear to be confined to the hollow stems, within which they cultivate colonies of the mealybugs. Mature trees, which reach 30 ft. or more in height, support ant colonies inside the hollow trunk and in all lateral branches, including the smallest, as well as in large hard carton nests constructed on the outside of the main trunk. Near these outside nests can generally be found small isolated colonies of the mealybugs, protected by loose carton coverings made by the ants, in cracks and crevices in the bark. Mealybugs from these " outside " colonies are less numerous, but noticeably larger, than those from colonies inside the trunk and branches. (Communicated by H. E. Box.)

The other extreme is presented by three individuals from *Ceiba pentandra* from the Gold Coast in which the greatest development of the dermal setae was found. The material unfortunately was very scanty, but the dermal setae appear to be longer than in any other form, even H.1201 and H.1350 (35-45) referred to above. Further material from this host plant is necessary before adequate comparisons can be made.

The foregoing detailed remarks have shown that the differences noted in the two lots of material described as *njalensis* and *exitiabilis* fall away now that a longer range of material has become available. The following points are also of significance:

1. Typical *exitiabilis* on coffee, the plant on which the original material of *njalensis* was collected, occurs in British Togoland.
2. Other specimens from Sierra Leone on cacao and *Homalium* agree more closely with *exitiabilis* as described than with *njalensis*.
3. The form most closely related to *njalensis* was found on *Canthium* in the Gold Coast. Yet other material from *Canthium*, even from the same plant, closely resembled *exitiabilis*.

It is unusual to have so much material of any one species complex, and the variation disclosed has presented a problem of considerable complexity. Not only have intermediate forms been found which bring together *njalensis* and *exitiabilis*, but other forms occur outside these limits which increase the range of variation to an even greater degree. It would be possible to select at least four lots which, divorced from the remainder of the material, might well be considered distinct, though closely allied, species. Yet the writer is satisfied that on taxonomic grounds *exitiabilis* and the range of material herein discussed represents a single, if variable, species for which the prior name of *njalensis*, Laing, will stand. No distinct form is associated exclusively with any one host plant or any given locality, and no form shows characters which are sufficiently constant in their difference from the type and other forms to provide a satisfactory basis for separation. Typical *exitiabilis* has been proven capable of transmitting two distinct strains of the "swollen shoot" virus under experimental conditions (Box, 1945, *loc. cit.*). It remains to be shown whether the various other forms of *njalensis* are equally capable of being vectors.

It is characteristic of the mealybugs under review that they are nearly always associated with certain ants, chiefly *Crematogaster, Pheidole* and *Camponotus* spp., which provide them with protective coverings and jealously guard the colonies. Mr. H. Donisthorpe has indentified much of this material and recently described five of the *Crematogaster* species as new. It was thought that there might be some correlation between the species of ant and the form of the mealybug with which it is associated but no such correlation can be detected.

The species *njalensis*, as here recognised, occurs in Sierra Leone, Ivory Coast, Gold Coast, French and British Togoland and Nigeria west of the River Niger. It seems probable that it is an indigenous species with a continuous distribution from Sierra Leone right through to south-western Nigeria. The effect of the ants would be to localise colonies and to tend to prevent any rapid spread, and one might be tempted to regard the problem as illustrating a species in process of breaking up were it not for the discovery of two such different forms associated with one ant colony on the same *Canthium* plant and the fact that no one form is exclusively associated with any particular habitat or locality. It must, therefore, be regarded as an unstable species in which, however, dermal pores of an unusual type and arrangement are invariably present.

It is recognised that although no taxonomic grounds have been detected to warrant the subdivision of *njalensis* into two or more distinct species further knowledge may result in the establishment of biological forms. It is felt, however, that in view of the great economic importance of the species in question, it is desirable to place on record this discussion of the taxonomic aspects of the problem.

I am indebted to Mr. Box for checking the host plants and localities here recorded and for some valuable comments which have been incorporated in the paper.

THE USE OF DDT AS A MOSQUITO LARVICIDE ON STILL WATERS.

By Major C. R. Ribbands, R.A.M.C.

Introduction.

In February, 1944, No. 2 Entomological Field Unit, R.A.M.C., arrived in India with the first consignment of DDT (dichlor-diphenyl-trichlorethane) to be used there for research purposes. Experiments to determine the larvicidal effects of this substance were carried out by the unit, of which I was Commanding Officer.

The first series of experiments, designed to demonstrate the minimum lethal dose and the spreading power of DDT in oil on still waters, were conducted at Nikaweratiya, Ceylon, in April, 1944. Another series, to investigate the residual larvicidal effect of DDT, were carried out at Gologhat, Assam, in October, 1944. Most of the routine work involved in these experiments was performed by Sgt. Aspey, Sgt. Hawkins, and Pte. Shaw, and by Mr. Sirapragasam, a Sanitary Inspector of the Ceylon Medical Department.

I regret that, as I have only had access to summaries of a few reports on other trials of DDT, I cannot compare results detailed below with those of workers elsewhere.

Methods.

The DDT used was a crude product, para-para content 73 per cent. The concentration in oil solution was 5 per cent. (8 oz. DDT per Imperial gallon), and the solutions were applied by pipette. When applied as a dust, the weighed dose was mixed with about 50 times the quantity of wood ash immediately before application, and sprinkled on by hand. I understand that more efficient dusts can be made by mixing microtonised DDT with talc, but this method was not available.

The Minimum Dose of DDT in Oil.

A large number of rectangular pits, size 4 ft. × 3 ft., were dug in rows in a field. They filled with rain and seepage water and began to breed a mixed population of mosquitos. Approximately 80 per cent. of the Anopheline larvae were *Anopheles culicifacies* and *A. vagus,* and the rest were mainly *A. barbirostris,* with a few *A. hyrcanus* and *A. subpictus.* The Culicines were not identified.

For each experiment, 10 dips were made in each pit, and the pits were then treated with the appropriate dose of DDT and/or oil. They were then re-dipped in the same manner by the same person 18-24 hours later. The results are set out in Table I and show the effects of oil and DDT under conditions which may be considered optimum. They show that oils applied at the rate of 4 pints per acre had no deleterious effect on the mosquito population within 24 hours. Twice this quantity of oil caused a reduction, not necessarily significant. Five per cent. DDT applied in oil at doses at and above one pint per acre caused 100 per cent. mortality of both Anopheline and Culicine larvae within 24 hours. Five per cent. DDT applied in oil at doses of one-third and one-half pint per acre caused 90 per cent. mortality of Anopheline larvae and 56-85 of Culicine larvae within the same period. The DDT was applied in malariol, in kerosene, and in waste engine oil. Results were not recorded separately because it was found that the type of oil vehicle made no appreciable difference to the efficiency of the DDT. In the eleven experiments using 5 per cent. DDT at the rate of half pint per acre, DDT in waste engine oil was 100 per cent. effective on 3 out of 5 occasions, while DDT in kerosene produced 100 per cent. mortality twice in three times, and DDT in malariol once in three times. These differences are not significant.

TABLE I.

Lethal Effect of small Doses of DDT in Oil.

Dose in pints/acre	Total No. of Expts.	Number of Experiments and Type of Oil used			Anophelines			Culicines		
		Waste Engine Oil	Malariol	Kerosene	Before	After	Percentage reduction of larvae	Before	After	Percentage reduction of larvae
							%			%
Untreated	8				123	66	46	60	65	9 increase
Oil only, 4 pts.	4	2	1	1	44	23	48	52	97	87 increase
Oil only, 8 pts.	2	2	0	0	61	14	77	27	8	70
5% DDT in Oil, ⅓ pt. ...	4	2	1	1	188	16	91	158	24	85
do. do. ½ pt. ...	11	5	3	3	272	28	90	197	87	56
do. do. 1 pt. ...	2	2	0	0	41	1 pupa	100	44	0	100
do. do. 2 pts. ...	4	3	0	1	117	0	100	138	0	100
do. do. 4 pts. ...	4	2	1	1	103	0	100	64	0	100

TABLE II.

Lethal Effect of DDT and Paris Green Dusts.

Dose per acre	No. of Expts.	Anophelines				Culicines		
		Before	After	Number of 2nd–4th instar larvae After	Percentage reduction of larvae	Before	After	Percentage reduction of larvae
					%			%
Untreated	8	89	105	63	18 increase	33	56	70 increase
Paris Green, 2 oz.	2	53	15	7	72	31	39	26 increase
DDT 2 oz.	2	28	16	2	43	21	31	48 increase
Paris Green 4 oz.	3	52	16	4	69	120	64	47
DDT 4 oz.	3	49	8	0	84	137	49	64
Paris Green, 8 oz.	3	30	7	0	77	34	19	44
DDT 8 oz.	3	24	7	1	71	57	13	77
Paris Green, 1 lb.	4	29	8	0	72	26	3	88
DDT 1 lb.	4	49	9	0	82	34	36	6 increase

Comparison of Lethality of DDT and Paris Green Dusts.

The experimental conditions were similar to those described above. The results are set out in Table II. They show that under these optimum conditions there was little to choose between DDT and Paris Green (though the physical characteristics of Paris Green enable it to be applied more satisfactorily in dust form). In both cases complete abolition of larvae was not obtained after 24 hours, but there was a marked reduction. Of the Anophelines found 24 hours after application at concentrations of 8 oz. per acre and upwards, all (except one) were first-instar larvae, and had presumably hatched after the area was treated, so this concentration can be considered to have been effective at the time of application. Some older larvae survived at lesser concentrations, but applications of 2 oz. per acre caused a large reduction in their numbers.

The Residual Larvicidal Effect of DDT in Oil.

These experiments were conducted in Assam. The same technique was used except that dipping was continued at daily intervals. No rain fell during these experiments, which may be considered to have been conducted under optimum conditions for larvicidal action. The Anopheline population was predominantly *A. vagus*. The few Culicines obtained have been disregarded.

The results are recorded in Tables III and IV. The conclusions may be summarised as follows:—

1. *Absence of important ovicidal properties.*—Comparison of Tables III and IV shows that with the heavy doses of either waste oil or DDT in waste oil first-instar larvae were found ten days or more before larger larvae appeared in the pits. This result shows that any deterrent effect on the egg-laying female or any ovicidal effect which these treatments may produce is negligible. Absence of any marked ovicidal effect is proved by the presence of very small numbers of newly-hatched larvae soon after treatment with heavy doses (Table IV). For this reason the percentage reduction in 2nd to 4th-stage Anophelines is a better guide to the effectiveness of these larvicides than the percentage reduction of the whole Anopheline population, and the conclusions that follow are therefore based on the results given in Table III.

2. *Immediate larvicidal action.*—These results confirm the previous conclusion that a dose of 5 per cent. DDT in oil of 1 pint or more per acre can be 100 per cent. lethal, but shows that up to 5 per cent. of larvae may remain alive for 24 hours after treatment, although they afterwards die. A dose of 5 per cent. DDT in oil at the rate of only one-fifth pint per acre produced 75 per cent. mortality within one day, and 100 within three days. Although this dose was effective under optimum experimental conditions, I do not think that it would prove satisfactory in practice, where distribution might be more uneven and where rain and similar factors might lead to disintegration of the oil and chemical film. I consider that as a minimum standard of efficiency a larvicide should be at least 90 per cent. effective within 24 hours.

3. *The larvicidal effect of waste oil only.*—Doses of waste oil at rates up to 2 gallons per acre caused no diminution of the larger Anophelines up to 24 hours, but 4 pints per acre caused a 50 per cent. reduction after 48 hours, with no first-instar larvae present, and a 90 per cent. reduction by the fifth day. Two gallons per acre caused complete elimination by the fifth day, and 8 gallons per acre by the third day.

TABLE III.

Percentages of II–IV Instar Anophelines at Intervals after Treatment.

Dose per acre	No. of Expts.	Total No. before treatment	Percentage of pre-treatment number found in days after treatment											
			1	2	3	5	7	11	14	18	22	25	28	32
Untreated	12	103	189	108	233	?	75	67	85	62	41	53	55	?
Waste Oil only, 4 pints ...	2	18	156	44	56	11	5	72	39	66	162	178	100	78
do. do. 2 gals. ...	2	13	108	8	77	0	0	46	54	54	108	100	292	155
do. do. 8 gals. ...	2	18	33	11	0	0	0	0	0	0	0	0	17	28
5% DDT in Waste Oil—														
⅕ pint	3	40	23	7	0	2	10	17	15	35	20	65	90	37
1 pint	3	47	2	0	2	0	17	10	35	31	52	83	57	89
2 pints	3	37	3	0	0	0	0	0	27	19	38	84	108	59
4 pints	3	39	5	0	0	0	0	15	13	15	28	28	74	49
2 gals.	3	37	0	0	0	0	0	3	22	30	16	35	22	35
8 gals.	3	47	0	0	0	0	0	0	0	0	0	0	0	0

TABLE IV.

Numbers of First-Instar Anophelines at Intervals after Treatment.

Dose per acre	No. of Expts.	Total Number before treatment	Number in days after treatment											
			1	2	3	5	7	11	14	18	22	25	28	32
Untreated	12	39	20	19	0	?	75	50	33	50	60	85	32	?
Waste Oil only, 4 pints ...	2	5	0	1	0	2	1	3	7	3	14	25	3	6
do. do. 2 gals. ...	2	4	0	0	0	1	1	5	0	6	22	14	21	9
do. do. 8 gals. ...	2	5	0	0	0	0	0	0	0	10	3	3	0	0
5% DDT in Waste Oil—														
⅕ pint	3	16	0	1	0	1	2	1	2	19	17	23	12	0
1 pint	3	6	0	0	0	3	2	2	6	10	38	62	22	22
2 pints	3	5	0	0	0	2	1	2	2	9	23	42	12	10
4 pints	3	3	0	0	0	1	1	1	4	12	15	18	15	12
2 gals.	3	5	0	0	0	0	1	3	2	21	6	17	8	13
8 gals.	3	10	0	0	0	0	0	1	0	3	2	0	0	5

4. *Residual larvicidal effects.*—At a dose of 2 gallons per acre, both waste oil only and 5 per cent. DDT in waste oil were completely effective on the seventh day, but they allowed breeding by the eleventh day. Whereas waste oil in this dose seemed completely ineffective by the eleventh day, a similar dose of 5 per cent. DDT in waste oil kept the population down to 30 per cent. of pre-treatment level on the eighteenth day, and it remained subnormal for a month. No second—fourth-instar larvae were found until the twenty-eighth day using waste oil at the rate of 8 gallons per acre, although first instars were found on the eighteenth day and subsequent days. With 5 per cent. DDT in waste oil at the rate of 8 gallons per acre, no second—fourth-instar larvae were found during the 32 days of the experiment, although small numbers of first instars were found at intervals. This experiment had to be discontinued after the thirty-second day because the pits began to dry up.

The Spreading Power of DDT in Oil Solution.

These experiments were made in order to find the average distance through which small quantities of 5 per cent. DDT in waste engine oil would spread and exert a lethal effect when applied at a single point to various water surfaces. The experimental areas were straight edges of six irrigation tanks and ponds, and were selected because of the wide variety of conditions that they offered, ranging from open weed-free waters to ponds covered with a dense surface mat of *Pistia*. No waters were found on which DDT in oil failed to spread, and I consider that such waters would be of infrequent occurrence in Anopheline breeding areas, because most Anophelines frequent unpolluted waters.

In each case one edge of the pond was dipped at one foot intervals. The pond was treated by a dose of 5 per cent. DDT in waste engine oil which was applied by pipette at a selected point about 2 ft. from the edge of the pond. Twenty-four hours after treatment, the dipping was repeated by the same individual in the same manner as before. The records showed that on either side of the point of treatment, for varying distances, all larvae had been eliminated, and that usually there was an obvious partial elimination for a further distance. Beyond this area there was no significant difference between catches before and after treatment, and these areas were designated the control areas—results from them confirm the normal maintenance of the larval population in the untreated areas, and the effectiveness of the dippings. The treated stretches of water were all selected for their high larval infestation, and in most cases larvae were found at almost every dip. In those cases where larvae were more sparsely distributed, the distance from which the kill was measured was the last dip which contained larvae before treatment, but was free of them afterwards. The distance given for the kill is the sum of the two distances, on either side of the point of treatment, through which the kill was obtained. Kills less than 75 per cent. are not considered. The post-treatment records were obtained 24 hours after treatments.

Experiment 1.

Spreading on open, weed-free water.—One of the straight edges of a large irrigation tank, 2000 ft. wide and more than 2000 ft. long, was used. The bank sloped steeply, and the sparse vegetation was mostly grass, and seldom extended more than 6 in. from the edge. The rest of the water surface was weed-free and constantly rippled by wind. No Culicines were found in this tank. Three hours steady rain commenced 2 hours after treatment. The results are recorded in Table V.

Table V.

Spread of DDT in Oil on Open Weed-free Water. (Expt. 1.) Anopheline Larvae only

Untreated Control Length	Larvae before Treatments	Larvae after Treatments	Alteration
	317 in 699 ft. = 4·55 per 10 ft.	285 in 699 ft. = 4·07 per 10 ft.	10% reduction

Dose	Complete Kill		Partial Kill				Total Effect			
	Length in feet	Larvae before	Length in feet	Larvae		Kill	Length in feet	Larvae		Kill
				Before	After			Before	After	
						%				%
(a) 1 c.c.	10	12	50	84	20	76	60	96	20	79
(b) 2 c.c.	23	32	68	52	12	77	91	84	12	86
(c) 8 c.c.	40	26	—	—	—	—	40	26	—	100

In experiment (*c*) there was an additional 44 ft. of probable partial kill, with 55% reduction in II–IV instar larvae.

TABLE VI.

Spread of DDT in Oil on a Weedy Pond, free of Surface Vegetation. (Expt. 2.)

Untreated Control Length	Larvae before Treatments	Larvae after Treatments	Alteration
Anophelines	606 in 261 ft. = 23·3 per 10 ft.	404 in 261 ft. = 15·5 per 10 ft.	33% reduction
Culicines	88 in 265 ft. = 3·3 per 10 ft.	67 in 265 ft. = 2·5 per 10 ft.	24% reduction

Dose	Complete Kill		Partial Kill				Total Effect			
	Length in feet	Larvae Before	Length in feet	Larvae		Kill	Length in feet	Larvae		Kill
				Before	After			Before	After	
Anophelines :—						%				%
(*a*) 0·25 c.c	7	25	29	61	13	79	36	86	13	85
(*b*) 0·25 c.c.	15	9	4	4	1	75	19	13	1	92
(*c*) 1 c.c.	7	19	46	116	8	93	51	135	8	94
(*d*) 4 c.c.	20	112	47	153	8	95	67	265	8	97
(*e*) 8 c.c.	63	161	12	27	7	74	75	188	7	96
Culicines :—										
(*a*) 0·25 c.c.	4	4	—	—	—	—	4	4	—	100
(*d*) 4 c.c.	34	19	18	4	1	75	52	23	1	96
(*e*) 8 c.c.	86	52	—	—	—	—	86	52	—	100

In experiment (*e*) the number of Culicines was only sufficient to obtain a result on one side of the point of application. The result from this side has been doubled to give it equivalent value in the table.

Experiment 2.

Spreading on a weedy pond, without surface vegetation.—A shaded irrigation tank, 500 ft. long and more than 300 ft. wide, was used. The long straight edge had a narrow band of weeds and grass. The surface of the pond was mainly covered with floating sub-surface vegetation (*Myriophyllum* sp. ?) which probably interfered with free water movement, but was without floating surface leaves. Heavy rain fell for 30 minutes, and light rain for 2 hours, during the experiment. The Anopheline sample identified comprised 64 per cent. *A. hyrcanus,* 28 per cent. *A. jamesi* and 8 per cent. *A. barbirostris.* The results are recorded in Table VI.

Experiment 3.

Spreading on a weedy pond, with varied vegetation including water lilies.—The selected site was a portion of a very large irrigation tank, and contained very varied surface and sub-surface vegetation, including *Myriophyllum* sp. and small water lilies. This tank was frequented by buffalo, which may have waded into the experimental area between dippings. The weather was fine during the experiment. The Anopheline population comprised 82 per cent. *A. hyrcanus,* 14 per cent. *A. jamesi,* and 4 per cent. *A. subpictus.* The results are recorded in Table VII.

Experiment 4.

Spreading on a weedy pond 75 *per cent. covered with surface vegetation.*—This experiment was conducted on a rather shallow irrigation tank, which was more than 1500 ft. long and had a minimum width of 500 ft. The long straight edge was weedy, with short grasses and small patches of *Marsilea quadrifolia* and other plants. The water was still and the surface of the pond was approximately 75 per cent. covered with floating surface vegetation, principally *Isachne australis* and *Myriophyllum* species. The Anopheline population was predominantly *A. hyrcanus.* Culicines were only present at one end of the tank. There was no rain during experiments a, c, e, and g, but 30 minutes heavy rain and 2 hours light rain fell 4 hours after treatment during experiments b, d, f, and h. The results are recorded in Table VIII.

Experiment 5.

Spreading against maximum weed resistance.—Several straight stretches of the edge of an irrigation tank and a pond, the whole surfaces of which were tightly packed with rosettes of the Water Soldier, *Pistia stratiotes,* were used. The *Pistia* was not quite so densely packed in the stretches were experiments j, and k, were conducted, but even here the whole surface was completely covered with rosettes. The Anopheline population was predominantly *A. hyrcanus.* The weather was fine during experiments a, c, and f, but 30 minutes heavy rain and 2 hours light rain fell during experiments b, d, e, and g, and 2 hours steady rain during experiments h-l. The results are recorded in Table IX.

TABLE VII.

Spread of DDT in Oil on a Weedy Pond with Water Lilies. (Expt. 3.) Anopheline Larvae only.

Untreated Control Length	Larvae before Treatments	Larvae after Treatments	Alteration
	205 in 323 ft. = 6·4 per 10 ft.	150 in 323 ft. = 4·7 per 10 ft.	27% reduction

Dose	Complete Kill		Partial Kill				Total Effect			
	Length in feet	Larvae Before	Length in feet	Larvae		Kill	Length in feet	Larvae		Kill
				Before	After			Before	After	
						%				%
(a) 1 c.c.	28	13	21	12	3	75	49	25	3	88
(b) 4 c.c.	59	28	16	7	1	87	75	35	1	97

In experiment (*b*) there was an additional length of 50 ft. with a 51% reduction of Anopheline larvae.

TABLE VIII.

Spread of DDT in Oil on a Weedy Pond with Surface Vegetation. (Expt. 4.)

Untreated Control Length	Larvae before Treatments	Larvae after Treatments	Alteration
Anophelines	388 in 656 ft. = 5·9 per 10 ft.	397 in 656 ft. = 6·1 per 10 ft.	3% increase
Culicines	245 in 424 ft. = 5·8 per 10 ft.	315 in 424 ft. = 7·4 per 10 ft.	29% increase

Dose	Complete Kill		Partial Kill				Total Effect			
	Length in feet	Larvae Before	Length in feet	Larvae		Kill	Length in feet	Larvae		Kill
				Before	After			Before	After	
Anophelines :—						%				%
(*a*) 1·0 c.c.	41	42	6	8	2	75	47	50	2	96
(*b*) 1·0 c.c.	32	35	10	29	5	83	42	64	5	92
(*c*) 2·0 c.c.	65	48	—	—	—	—	65	48	—	100
(*d*) 2·0 c.c.	40	38	6	5	1	80	46	43	1	98
(*e*) 4·0 c.c.	70	20	—	—	—	—	70	20	—	100
(*f*) 4·0 c.c.	67	45	—	—	—	—	67	45	—	100
(*g*) 8·0 c.c.	100	24	—	—	—	—	100	24	—	100
(*h*) 8·0 c.c.	67	46	—	—	—	—	67	46	—	100
Culicines :—										
(*c*) 2·0 c.c.	36	5	—	—	—	—	36	5	—	100
(*g*) 8·0 c.c.	29	228	58	172	21	88	87	400	21	95
(*h*) 8·0 c.c.	97	18	—	—	—	—	97	18	—	100

In experiment (*h*) there was a 50% reduction in Anopheline larvae over an additional 30 ft.

TABLE IX.

Penetration of DDT in Oil against Maximum Weed Resistance. (Expt. 5.) Anopheline Larvae only

Untreated Control Length	Larvae before Treatments	Larvae after Treatments	Alteration
Expts. a–g	82 in 76 ft. = 10·8 per 10 ft.	68 in 76 ft. = 9·0 per 10 ft.	17% reduction

Dose	Complete Kill		Partial Kill				Total Effect			
	Length in feet	Larvae Before	Length in feet	Larvae		Kill	Length in feet	Larvae		Kill
				Before	After			Before	After	
						%				%
(a) 0·25 c.c.	12	12	—	—	—	—	12	12	—	100
(b) 0·25 c.c.	15	15	—	—	—	—	15	15	—	100
(c) 1 c.c.	7	2	9	21	2	91	16	23	4	83
(d) 1 c.c.	10	13	14	12	3	75	24	25	3	88
(e) 1 c.c.	10	3	—	—	—	—	10	3	—	100
(f) 4 c.c.	25	17	—	—	—	—	25	17	—	100
(g) 4 c.c.	27	34	—	—	—	—	27	34	—	100

Untreated Control Length	Larvae before Treatments	Larvae after Treatments	Alteration
Expts. h–l	155 in 106 ft. = 14·6 per 10 ft.	145 in 106 ft. = 13·7 per 10 ft.	6·5% reduction

Dose	Complete Kill		Partial Kill				Total Effect			
	Length in feet	Larvae Before	Length in feet	Larvae		Kill	Length in feet	Larvae		Kill
				Before	After			Before	After	
										%
(h) 0·25 c.c.	13+	32	—	—	—	—	13+	32	—	100
(j) 1 c.c.	20	82	—	—	—	—	20	82	—	100
(k) 1 c.c.	20	34	—	—	—	—	20	34	—	100
(l) 4 c.c.	29	132	—	—	—	—	29	132	—	100

Summary of experiments on the spreading of DDT in oil solution.

The experimental results are summarised in Tables X-XIII, which show the types of breeding places, the weather during the experiments, and the distances of both complete and 75 per cent. kill, of both Anophelines and Culicines, for the various doses of DDT that were used. These results show that the distance of lethal penetration was greatest in ponds containing moderate quantities of surface vegetation, and least in those densely packed with *Pistia*, and in completely open water. In the latter case the film was probably dispersed too rapidly for high percentage

TABLE X.

Distance of Complete Anopheline Kill.

Expt.	Type of Pond	Weather	Distance of Complete Anopheline Kill, in feet				
			½ c.c.	1 c.c.	2 c.c.	4 c.c.	8 c.c.
1	Open Water	3 hours Rain	—	10	23	—	40
2	Weedy Pond	2½ hours Rain ...	15	—	—	—	—
2	,, ,, ...	,, ,, ...	7	7	—	29	63
3	Weedy Pond	Fine	—	28	—	59	—
4	Weedy Pond	Fine	—	41	65	70	100
4	,, ,, ...	½ hr. Heavy, and 2 hours Light Rain	—	32	40	67	67
5	*Pistia* covered Pond ...	Fine	12	7	—	25	—
5	,, ,, ,, ...	2½ hours Rain ...	15	10	—	27	—
5	,, ,, ,, ...	,, ,, ...	—	10	—	—	—
5	,, ,, ,, ...	2 hours Rain	13+	20	—	29	—
5	,, ,, ,, ...	,, ,, ...	—	20	—	—	—
	MINIMUM LENGTH OF KILL		7	7	23	25	40
	AVERAGE LENGTH OF KILL		12	19	42	44	67

TABLE XI.

Distance of Complete Culicine Kill.

Expt.	Type of Pond	Weather	Distance of Complete Culicine Kill, in feet			
			½ c.c.	1 c.c.	4 c.c.	8 c.c.
2	Weedy Pond	2½ hours Rain	4	—	34	86
4	Weedy Pond	Fine	—	—	—	29
4	,, ,, ...	½ hour Heavy Rain and 2 hours Light Rain ...	—	43	—	97
5	*Pistia* covered Pond ...	Fine	5	7	11	—
5	,, ,, ,, ...	2½ hours Rain	10	10	15	—
5	,, ,, ,, ...	,, ,, ...	—	4	—	—
5	,, ,, ,, ...	2 hours Rain	3	25	18	—
5	,, ,, ,, ...	,, ,, ...	—	15	—	—
	MINIMUM LENGTH OF KILL		3	4	11	29
	AVERAGE LENGTH OF KILL		5	17	19	71
	AVERAGE LENGTH OF ANOPHELINE KILL in same Experiments		12	19	41	76

Table XII.

Distance of at least 75 per cent. Anopheline Kill.

Expt.	Type of Pond	Weather	Distance of at least 75 per cent. Anopheline Kill, in feet				
			¼ c.c.	1 c.c.	2 c.c.	4 c.c.	8 c.c.
1	Open Water	3 hours Rain	—	60	91	—	40
2	Weedy Pond	2½ hours Rain ...	19	—	—	—	—
2	,, ,, ...	,, ,, ...	36	51	—	67	75
3	Weedy Pond	Fine	—	49	—	75	—
4	Weedy Pond	Fine	—	47	65	70	100
4	,, ,, ...	½ hour Heavy Rain and 2 hours Light Rain	—	42	46	67	67
5	*Pistia* covered Pond ...	Fine	12	16	—	25	—
5	,, ,, ,, ...	2½ hours Rain ...	15	24	—	27	—
5	,, ,, ,, ...	,, ,, ...	—	10	—	—	—
5	,, ,, ,, ...	2 hours Rain	13+	20	—	29	—
5	,, ,, ,, ...	,, ,, ...	—	20	—	—	—
Minimum Length for at least 75 per cent. Kill			12	10	46	25	40
Average Length for at least 75 per cent. Kill			19	35	67	51	71

Table XIII.

Distance of at least 75 per cent. Culicine Kill.

Expt.	Type of Pond	Weather	Distance of at least 75 per cent. Culicine Kill, in feet			
			¼ c.c.	1 c.c.	4 c.c.	8 c.c.
2	Weedy Pond	2½ hours Rain	4	—	52	86
4	Weedy Pond	Fine	—	—	—	87
4	,, ,, ...	½ hour Heavy Rain and 2 hours Light Rain ...	—	47	—	97
5	*Pistia* covered Pond ...	Fine	8	10	11	—
5	,, ,, ,, ...	2½ hours Rain	10	10	22	—
5	,, ,, ,, ...	,, ,, ...	—	6	—	—
5	,, ,, ,, ...	2 hours Rain	13	25	30	—
5	,, ,, ,, ...	,, ,, ...	—	15	—	—
Minimum Length for at least 75 per cent. Kill			4	6	11	86
Average Length for at least 75 per cent. Kill			9	19	29	90
Average Length for 75 per cent. Anopheline Kill in same Experiments			19	30	47	81

kills to be achieved over a long distance. The minimum lengths of edge completely cleared of Anophelines were, 7 ft. by 0.25 c.c. and 1 c.c., 23 ft. by 2 c.c., 25 ft. by 4 c.c., and 40 ft. by 8 c.c. The average length through which a kill of at least 75 per cent. of the Anophelines present was attained was 12 ft. by 0.25 c.c., 10 ft. by 1 c.c., 46 ft. by 2 c.c., 25 ft. by 4 c.c., and 40 ft. by 8 c.c.

The marked penetration of the insecticide is a property which will have most important practical consequences. Experiments conducted by Professor N. K. Adam show that the addition of DDT does not increase the spreading pressure of oils, as tested in an Adam-Langmuir trough, so we must consider that the oil alone would have spread over the distance through which the DDT solution has been demonstrated by these experiments to be lethal.

When another liquid spreads over a water surface, it spreads first as a film of visible thickness, and ultimately extends until this film is a monomolecular one, or until the whole surface is covered. The final stage of equilibrium is a monomolecular film over the whole surface, with any excess aggregated into a drop (Devaux, 1912; Hardy, 1913). Mosquito larvae are not killed by a monomolecular film of oil, and the larvicidal properties of good oil films are due to the fact that they are mixtures which persist as thick films for a long time before the final equilibruim is reached (Hardy, *ibid.*).

It seems likely that an essential advantage of DDT solutions over the larvicidal oils which have previously been employed is that the former are lethal in the stable and far-reaching monomolecular film, while the latter are only lethal in the less stable and less easily obtainable thick film.

Table XI shows that Anophelines were more vulnerable to the insecticide than Culicines, but that with the doses of 1 c.c. and 8 c.c. the difference in effectiveness was not significant.

With the minimum dose of 0.25 c.c. the insecticide was markedly less effective against Culicines in all four experiments and the average distance of Culicine kill was only 40 per cent. of that of Anopheline kill. The preceding experiments have indicated that Culicines are slightly less vulnerable to DDT than Anophelines when it is used at border line concentrations. This result may therefore have occurred because the very small dose had spread out to cover a much greater relative area than the larger doses, and had therefore produced a low concentration of DDT, or an interrupted film, which was lethal to Anophelines but less damaging, or less quickly damaging, to Culicines.

The results indicate that rain has no marked and consistent effect on the immediate larvicidal action of DDT. In experiment 4, which was conducted on fairly open water, rainfall reduced the length of kill, but in experiment 5, which was on water densely covered with *Pistia*, it seemed to have the converse effect—possibly because in the latter case it increased the circulation on the water surface but was unable to damage the oil film.

Practical Application of DDT in Oil to Still Water.

The results detailed in the preceding section indicated that the spreading power of DDT in oil was so considerable that it would be sufficient to treat suitable breeding areas with a dose applied at intervals, instead of a spray to cover the whole surface.

The essential requirement before such a method of treatment can be used is that the water surface, however much interrupted by vegetation, must not consist of completely separated water areas, such as would be provided by breeding places such as hoof marks.

The experimental area used to test a simple method of treatment by DDT was a marsh of irregular outline, size approximately 50 ft. × 190 ft., of surface area calculated to be 1,080 sq. yds. The water surface was not sub-divided, but it was much interrupted by vegetation of all sorts, in large varied patches of long grasses, rushes, thick short grasses and floating weeds. This area contained samples of all local types of dense marshy vegetation. On 10th April, 1944, it was treated with 216 c.c. of 5 per cent. DDT in waste engine oil, a dose equal to 2 pints per acre. The liquid was measured out into a 3 in. × 1 in. specimen tube in doses of approximately 5 c.c., and applied at 12 ft. intervals round the perimeter. Each dose was flung from the tube and splashed in a line across the marsh surface. 256 dips were made at 1 ft. intervals in various sectors of the marsh both on the day before treatment and 24 hours after treatment. The catch before treatment was 25 first-instar and 124 larger Anophelines, and 643 Culicines. 24 hours after treatment no Anophelines were caught, and only 7 Culicines. This marsh was redipped in the same manner one week after treatment, and on this occasion 190 Culicines were obtained, but only 3 first-instar and one larger Anopheline. This result indicates that the residual effect of DDT is much less marked against Culicines than against Anophelines.

This experiment shows that DDT in oil can be a completely effective larvicide in many breeding areas when it is applied without the use of any form of apparatus other than a small container.

Suitable Apparatus for applying DDT in Oil to Still Water.

Although it is not necessary for satisfactory application of DDT in oil, it is convenient to use a simple apparatus which will throw a roughly measured dose to a distance.

Captain Umar-Ud-Din, Officer Commanding No. 9 Indian Anti-Malaria Unit, has demonstrated that various patterns of RKW oil squirts are very suitable for this purpose, and I think that it would be difficult to devise a more simple or more convenient apparatus than a pump of this type, preferably modified by having a larger reservoir. The pumps that were tested had an average output of 1.3 c.c. per squirt, and sent a jet of oil over a distance of at least 15 ft. If the solution was squirted on to a pond at 8 ft. intervals, a 15 ft. wide band round its edge would receive a dose at the rate of one pint per acre.

Conclusions.

LETHAL DOSE OF DDT.

1. Five per cent. DDT in oil applied at the rate of 1 pint per acre (= 1 oz. DDT per acre) was lethal to both Anopheline and Culicine larvae within 24 hours, under optimum conditions.

2. Five per cent. DDT in oil, applied at the rate of one-fifth pint per acre, produced 75 per cent. mortality within one day, and 100 within 3 days.

3. Waste engine oil alone, at the rate of 2 gallons per acre, caused no diminution of the large Anophelines within 24 hours, but provided complete elimination by the fifth day.

4. Waste oil alone, applied at the rate of 8 gallons per acre, under optimum conditions without rain, prevented the development of Anopheline larvae for 28 days. This effect was emphasised when 5 per cent. DDT in waste oil was used.

5. The residual effects of DDT in oil on Anopheline larvae were much greater than those on Culicine larvae. The initial lethal effects were slightly greater among Anopheline larvae.

6. DDT was equally effective, whether dissolved in waste engine oil, malariol, or kerosene.

7. DDT in oil had no important ovicidal or egg-laying deterrent properties.

8. DDT and Paris Green, when applied in dusts, were similar in their effects. The minimum dose which was effective within one day was at the rate of 8 ozs. per acre.

Spreading Power of DDT in Oil.

9. The most important property of DDT in oil is that it seems to be lethal to larvae in a monomolecular film. This enables it to spread rapidly over a very large area from the point of application, and enables doses to be applied at intervals only.

10. When 5 per cent. DDT in waste oil was applied to the edges of various types of pond the minimum lengths of edge completely cleared of Anophelines were 7ft. by 0.25 c.c. and 1 c.c., 23 ft. by 2 c.c., 25 ft. by 4 c.c., and 40 ft. by 8 c.c. The average lengths were considerably greater than this.

11. The greatest distance of lethal penetration was found in ponds containing moderate quantities of surface vegetation, and least in those densely packed with *Pistia*, and in completely open water.

12. Rain had no consistent effect on the penetration of doses of DDT in oil. On fairly open water it reduced the length of kill, but on water densely packed with *Pistia* it had the converse effect.

Practical Methods for the use of DDT in Oil.

13. Larvae were successfully eliminated from a large marsh by throwing 5 per cent. DDT in oil on to the water surface at 12 ft. intervals, in a dose at the rate of 2 pints per acre.

14. No apparatus is necessary when such a method is used, but RKW oil squirts provide a simple and convenient means for distributing a measured dose.

References.

Devaux (1912). J. Phys. Radium, **2**, p. 891.

Hardy, W. B. (1913). Proc. roy. Soc. (A), **88**, p. 315.

(Both quoted by Adam, N. K. (1941). The Physics and Chemistry of Surfaces, London.)

CEYLON EUPLECTRINI (HYM.).

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Ferrière (1941) in his study of the Euplectrini (Chalcidoidea, Eulophidae) has described three yellow species from Ceylon, all parasites of nettle grubs (Limacodidae) from tea, and has erected three genera to accommodate them. They are *Neoplectrus maculatus* (1940), *Platyplectrus natadae* (1941), and *Metaplectrus thoseae* (1941). In April, 1944, the writer obtained two females from *Thosea cervina,* and at first sight they were thought to be *Metaplectrus thoseae,* but closer examination showed them to differ from Ferrière's description in several important respects. In order to ascertain their systematic position the following brief study of Ceylon specimens was undertaken.

In his "attempt to find good characters to distinguish different species" of Euplectrini, Ferrière (1941) directed attention to the carinae of the propodeum. In his key to the genera he first separates *Neoplectrus* from other genera, because its propodeum has two longitudinal carinae which enclose a median area (fig. 1*a*). Other genera have only one median carina.

In the group with one median carina on the propodeum, *Metaplectrus* is recognised by the spurs of the hind tibiae being not longer than the metatarsus, and *Platyplectrus* by the thorax being almost flat above—the mesonotum, scutellum, metanotum and propodeum being on approximately the same horizontal level. Other genera, *Euplectromorpha* and *Euplectrus* have black bodies, with or without yellow markings and with distinctly oblique propodea.

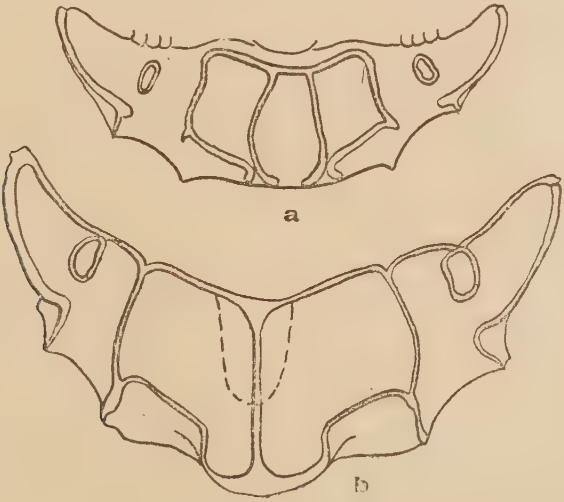

Fig. 1. (*a*) Propodeum of *Neoplectrus maculatus.*
(*b*) Propodeum of *Platyplectrus natadae.*
(× 106 approx.)

In a note below his key to the species of *Platyplectrus,* Ferrière (1941, p. 2) states "it is possible that *Euplectrus nigromaculatus,* Ashmead, and *Euplectrus flavescens,* Crawford, belong to this group (see Appendix)". In the appendix of *Euplectrus* species from Asia, which had not been included in his revision (p. 46), is given Crawford's description of *E. flavescens*, which includes the following: " propodeum with a median and lateral carina, being areolated." Below the description is a note stating " the complete areolation of the propodeum distinguishes this from other species of the Oriental region in which yellow is the predominating colour." Crawford makes no mention of *E. flavescens* having a flat thorax with the propodeum on the same level, an important characteristic of the genus *Platyplectrus*. On the other hand Ferrière makes no mention of the areolation of the propodeum being characteristic of *Platyplectrus*. He describes the *Platyplectrus* propodeum as " with a strong median carina elevated at base where it forms often a translucent protuberance." *E. flavescens* has a similar protuberance which Crawford describes as " basal lip of propodeum strongly produced ". This basal lip of the propodeum is not uncommon in the EUPLECTRINI, as Crawford in his description of *Euplectrus medanensis* gives " propodeum with the usual median carina and basal lip " (Ferrière, 1941, p. 45).

It is still more difficult to see why *Euplectrus nigromaculatus*, Ashmead, might better be placed in the genus *Platyplectrus*, as the description (p. 44) is so brief that no mention is made of the propodeum, its basal lip, nor of the thorax being flat.

Amongst the generic characters of *Metaplectrus* is " propodeum short with distinct median and lateral carinae ". The propodeum of *M. thoseae* (the only species of the genus) is described as " smooth and shining with a median carina which fuses into a basal transverse carina, and lateral carinae which converge behind, forming two enclosed areae." Evidently *E. flavescens* with its areolated propodeum might equally well be placed in this genus but for the presence of long spurs on the hind tibiae. The writer, however, has no intention of attempting to find a more suitable genus to which to transfer *E. flavescens* without a re-examination of the specimens; the subject is discussed mainly because a similar problem arises concerning the specimens under review.

The two females collected in April, 1944, mentioned in the first paragraph and to be described below, have an areolated but oblique propodeum and long tibial spurs. The oblique propodeum and long spurs appear to exclude the specimens from *Platyplectrus* and *Metaplectrus* respectively, so it appeared advisable to examine further all available Ceylon specimens of these genera before accepting such conclusions.

Platyplectrus natadae, Ferrière.

This species, the genotype, is frequently found as a parasite of nettle grubs in the Passara district. Ferrière has described the propodeum as " horizontal, smooth, narrowed behind, with a strong median carina, surmounted at base by a translucent, tongue-like protuberance; lateral carinae distinct."

The propodeum is illustrated in fig. 1*b*, from which may be seen that there are two lateral carinae arising from the basal carina and running almost parallel with it to the posterior edge of the propodeum. In addition there are two narrow carinae running along the posterior margin of the black area of the propodeum, so joining the lateral with the broadened apex of the median carina. In this way two median areae are formed, the spiracles being exterior to them.

Of the four known species of *Platyplectrus* one only, *P. natadae*, is from Ceylon. *P. orthocraspedae* is said to have " lateral carinae slightly curved, reaching behind in transverse furrows ". The lateral carinae of *P. ornatus* are " not very distinct ending behind in deep furrows", whereas no mention is made of *P. capensis* having any lateral carinae on the propodeum. It is evident that lateral carinae are usual in *Platyplectrus* but in no instance are they stated to *converge* behind.

Metaplectrus thoseae, Ferrière.

Although I have not been able to examine any of the specimens of the collections described by Ferrière, there are in this Institute's collection several specimens that undoubtedly belong to the genus *Metaplectrus,* and one lot, P.280, is undoubtedly *M. thoseae.* This collection (P.280) is marked "ex *Thosea cervina,* Passara, July, 1937," and consists of 15 insects (12 ♀ and 3 ♂). They are slightly larger than the type specimens, measuring 1.7-2.1 mm. with an average (of 12) of 1.8 mm., and there is rather more black on them. The black area of the occiput is rather more than "a small spot"; there are black spots on the sides of the metanotum and near the spiracles of the propodeum, and the dark area of the abdomen extends over the posterior third except for the very tip. Otherwise, they agree closely with Ferrière's description of *M. thoseae,* particularly as regards the short tibial spurs, the almost rectangular pronotum, the short rounded abdomen, and the lateral carinae of the propodeum. There were no males is Ferrière's collection, so the following short description may be of interest.

♂: Length 1.5-1.7 mm., slightly smaller than female. Body yellow, with the following areas only black: transverse carina of pronotom, a spot under the tegulae, and posterior third of abdomen except the tip. Antennae entirely yellow and somewhat thinner. Abdomen narrower and shorter. Otherwise as for female. Ceylon, Passara, 3 ♂, July, 1937, ex *Thosea cervina.*

All the specimens of this collection, both male and female, have one tibial spur only, though most EUPLECTRINI have two, one longer than the other. Ferrière makes no specific mention of the absence of the longer spur in *Metaplectrus,* though he speaks of "spur of hind tibiae" being short, whereas in descriptions of species of other genera, e.g., *Neoplectrus areolatus,* he refers to "the longest tibial spur". The solitary tibial spur would appear to be the most useful distinguishing character of this genus (fig. 2, *a*).

The propodeum is as described by Ferrière, "smooth and shining with a median carina which fuses into a basal transverse carina, and lateral carinae which converge behind, forming two enclosed areae." The lateral carinae are fused to the basal carina near the spiracles, and run longitudinally but unlike those of *Platyplectrus natadae* they stop short of the posterior edge of the propodeum; they then turn sharply and converge on the median carina at its apex. The converging carinae probably correspond to what in *Platyplectrus* were termed the posterior carinae. The propodeum is very similar to that of *M. solitarius* shown in fig. 2, *c*.

With the 15 insects of P.280 is the *Thosea* exoskeleton from which they emerged. On the ventral side of it are the remains of 17 pupal skins, so the evidence is clear that this species is gregarious in its larval and pupal stages, like *Euplectrus platyhypenae, E. comstocki, E. bicolor,* and *E. agaristae* (Clausen 1940).

Metaplectrus solitarius, sp.n.

In his description of *M. thoseae,* Ferrière states "but two specimens from Ceylon and Sumatra are somewhat darker" and proceeds to enumerate the additional black parts. In this Institute's collection are similar specimens numbered "P.279 (2 ♀) ex *Thosea cervina,* Passara, October, 1938," and "P.440 (2 ♀ 1 ♂) ex *Narosa* May-June, 1942." Collection P.440 is of particular interest because it includes three exoskeletons each of which carries the remains of one pupal skin only. This evidence clearly suggests a solitary habit like that of *Neoplectrus maculatus* (Gadd & Fonseka 1944). It will be shown elsewhere that *Platyplectrus natadae* and *Autoplectrus taprobanes* are also solitary, and that where two or more eggs are laid on a host only one survives; so the occurrence of one parasite per host is not merely by chance. Ferrière saw two specimens only, one each from Ceylon and Sumatra. Incidentally, the one insect from Sumatra, judging from his list of material examined, was the sole specimen of the genus from that source. It seems unlikely, therefore, that the solitary dark specimen from Ceylon emerged with lighter coloured insects, the typical *M. thoseae,* from one host.

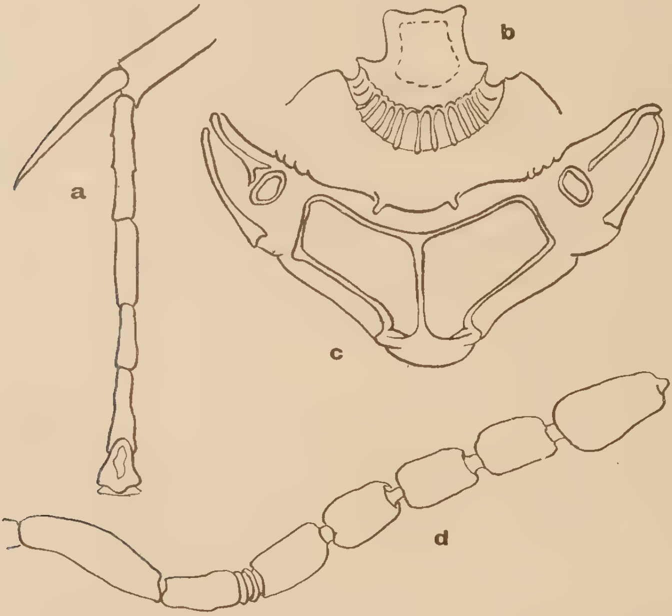

FIG. 2. *Metaplectrus solitarius* (*a*) tibial spur; (*b*) abdominal groove (*c*) propodeum; (*d*) antenna ♀. (× 106 approx.)

In addition to the differences in colour markings enumerated by Ferrière, specimens P.279 and P.440 are somewhat larger, the abdomen is more triangular and when measured from the petiole is nearly the same length as the thorax, whereas in *M. thoseae* it is only half the length of the thorax. These morphological differences together with the marked difference in habit are sufficient to constitute a definite species, for which I propose the name *Metaplectrus solitarius.*

The arrangement of the carinae on the propodeum is as shown in fig. 2, *c,* and is very similar to that of *M. thoseae.* The propodeum is oblique and the areae within the carinae are almost flat. There is no tongue-like protuberance at the base of the median carina, though it is somewhat thickened vertically in this region.

In microscope preparations of the whole insect mounted in Berlese's fluid, it may be seen that there are two ring joints (fig. 2, *d*) between the pedicel and first funicle joint. Ring joints possibly are not unusual in EUPLECTRINI, as they have also been observed in *M. thoseae* and *Platyplectrus natadae.*

In the groove near the base of the abdomen, where it adjoins the petiole, is a circlet of black ridges (fig. 2, *b*). Similar, but yellow, ridges are to be seen in *M. thoseae,* but the grooves of *Platyplectrus natadae,* and *Neoplectrus maculatus* are smooth.

Description.

♀ Length 2.0-2.3 mm. Body yellow, with the following areas black: two black lines on face covered by the scapes; two or more small spots close to ocelli; a large part of the occiput; anterior surface of pronotum, including the transverse carina; a line along the anterior margin of scutellum; large spots under tegulae, on sides of metanotum and near spiracles of propodeum—the last mentioned may unite to form a band across the base of propodeum, on sides of abdomen extending over posterior half of dorsal surface but not reaching the tip; a small spot at tip of abdomen. The following areas are brownish; anterior part of mesonotum, median area of scutellum and anterior part of abdomen. Legs light yellow. Antenna brown, scape and pedicel yellow.

Head transverse, vertex with sparse black ciliae; ocelli in a low triangle, the lateral closer to the front ocellus than to the eye margin. Eyes rounded, ciliate. Cheeks converging strongly towards the mouth. Antennae inserted at the lower eye level; scape not reaching the front ocellus, four times as long as broad; pedicel nearly twice as long as broad and less than half the length of scape; two ring joints, very small; first funicle joint rather longer and broader than the pedicel; the following joints slightly shorter, one and half times as long as broad; club one and a half times as long as the preceding joint. Pronotum strongly carinated in front, almost rectangular and as long as the mesonotum, finely rugulose, covered with fine ciliae and with a row of longer ciliae behind; mesonotum finely rugulose, ciliate more densely in front and with a row of long ciliae in a straight line along the posterior margin, parapsidal furrows deep. Scutellum reticulose over the whole surface, with four long ciliae, black at base; longitudinal furrows distinct. Propodeum oblique, smooth and shining, with median and lateral carinae, the latter converging behind to form two enclosed areae which are almost flat, median carina thickened vertically at its base, basal lip absent. Wings, long, ciliate, with brown veins; marginal and submarginal veins of equal length; stigmal vein about one-third of the marginal; postmarginal vein one and a half to twice the length of the stigmal. Hind legs with one tibial spur only, which is about the same length as the first tarsal joint. Abdomen smooth and shining, slightly shorter than thorax, broadest near the base and tapering gradually to the tip. Ovipositor protruding.

♂ Similar to female except for the abdomen, which is shorter and only half the length of the thorax, truncate, almost square, terminating in a short point; the posterior half is black.

Ceylon, Passara, 2 ♀ (P.279), October, 1938, ex *Thosea cervina;* 2 ♀ 1 ♂ (P.440), May/June, 1942, ex *Narosa conspersa.*

Autoplectrus taprobanes, gen. et sp. n.

The two females mentioned in the first paragraph have been used for experiments in the laboratory, but so far, only male offspring have been obtained. In this Institute's collection are two other females marked " P.99 ex *Spatulifimbria castaneiceps* November, 1938. Passara " which undoubtedly belong to the same species.

The arrangement of the carinae on the propodeum (fig. 3, *c*) is very similar to that of *Metaplectrus solitarius,* but the area enclosed by the lateral carinae is markedly convex. The groove at the base of the abdomen (fig. 3, *b*) is smooth, and there are no ring joints on the antennae (fig. 3, *d*). The tibiae of the hind legs carry two spurs each, the longer being as long as the first two tarsal joints together (fig. 3, *a*). This character together with the rounded pronotum prevent the inclusion of this species in the genus *Metaplectrus*. Although the propodeum has a short translucent basal tongue, it is markedly convex and oblique and the arrangement of the carinae is different from that of *Platyplectrus*. It seems advisable, therefore, to create a new genus for its accommodation, and the name *Autoplectrus taprobanes* is here proposed for the species. In habit it is solitary.

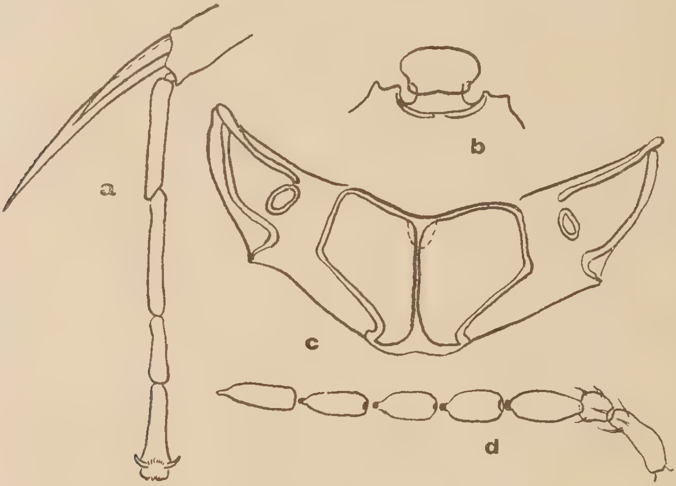

FIG. 3. *Autoplectrus taprobanes* (*a*) tibial spur; (*b*) abdominal groove; (*c*) propodeum; (*d*) antenna ♂. (× 106 approx.)

Autoplectrus, gen. n.

Body mainly yellow. Eyes not or only sparsely ciliate. Pronotum rounded in front. Scutellum with narrow longitudinal furrows. Propodeum short, oblique, with strong median and lateral carinae which converge behind, forming two enclosed areae. Abdomen, almost as long as the thorax. Petiole short. Longer spur of hind tibiae about as long as the first two tarsal joints together.

Genotype:—*Autoplectrus taprobanes,* sp. n.

Differs from *Metaplectrus* in having long tibial spurs and a rounded pronotum, and from *Platyplectrus* in having a rounded pronotum and a markedly oblique propodeum, with lateral carinae converging before reaching the posterior margin.

Autoplectrus taprobanes, sp. n.

♀ Length 2.5-3.0 mm. Body orange yellow, except for small black spots under the tegulae and at the tip of abdomen, and brownish bars at the sides of the abdomen. Antennae brown with small black spots between the joints; scape and pedicel yellow. Legs light yellow.

Head transverse, sparsely ciliate; vertex smooth, without distinct margin; ocelli in a low triangle bordering an elevated area, the lateral closer to the front ocellus than to the eye margin. Eyes rounded, frequently mottled with brown areas and with a few short ciliae. In living specimens the eyes are yellow and transparent, black retinulae being visible. Cheeks converging strongly towards the mouth.

Antennae inserted at lower eye level; scape narrow, not reaching the front ocellus; pedicel about twice as long as broad; first funicle joint twice the length of the pedicel; the following joints slightly shorter, about one and a half times as long as broad; club about the same size as the preceding joint. Prothorax rounded in front, as long as the mesonotum, finely rugulose, covered with short dark ciliae and with a row of longer ciliae behind. Mesonotum transverse with a longitudinal median carina, minutely punctate, sparsely ciliate with a row of 6 or 8 longer ciliae behind. Scutellum broad, finely reticulose above, almost smooth at the sides, with distinct longitudinal furrows. Propodeum oblique, smooth and shining, with median carina surmounted at base by a very small translucent tongue-like protuberance, lateral carinae converging behind; area bounded by basal and lateral carinae convex. Petiole short, broader than long. Wings large; marginal vein slightly longer than the submarginal vein; stigmal vein one-quarter the length of the marginal and about half the length of the post-marginal vein. Longer tibial spur of the hind leg twice the length of the first tarsal joint, and about as long as the first two tarsal joints together; shorter spur rather more than half the length of the longer. Abdomen elongate, narrower and shorter than the thorax, tapering to a point behind; ovipositor not protruding.

♂ Smaller, 1.4-1.7 mm. long. Colour on abdomen absent or less distinct, and the dot at the tip of the abdomen is absent. Antennae entirely yellow except for black dots between the joints, less robust; club a little longer than the preceding joint. Otherwise similar to female.

Ceylon: Passara, 2: ♀, November, 1938, *ex* larvae of *Spatulifimbria castaneiceps* (P.99); 2 ♀, April, 1944, *ex* larvae of *Thosea cervina* (P. 441); numerous ♂ bred from P.441.

References.

Clausen, C.P. (1940). Entomophagous Insects. New York and London.

Ferrière, C. (1940). On some parasites and hyperparasites of *Artona catoxantha* Hamp.—Bull. ent. Res., **31**, pp. 131-139.

———. (1941). New species of Euplectrini from Europe, Africa and Asia.—Bull. ent. Res., **32**, pp. 17-48.

Gadd, C. H. & Fonseka, W. T. (1944). *Neoplectrus maculatus* Ferrière: a predator and parasite of *Natada nararia* Mo. and other nettle grubs.—Ceylon J. Sci. (B), (*In press*).

NOTES ON THE BIONOMICS OF *HIEROGLYPHUS NIGROREPLETUS*, BOLIVAR (ORTHOPTERA, ACRIDIDAE) AT BENARES, UNITED PROVINCES, INDIA.*

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Zoological Survey of India.

Introduction.

Since the recognition by Bolivar (1912) of *Hieroglyphus nigrorepletus* as a distinct species, Coleman's (1914) note and Uvarov's (1922) valuable revision of the rice grasshoppers, it has been clear that in the earlier literature this species has been confused with *H. banian*, F., chiefly under the name of *H. furcifer*, Serv., while *H. bettoni*, Kirby, 1914, and *H. vastator*, Carl, 1916, are synonyms.

The available information regarding *H. nigrorepletus* as a pest is scanty. Fletcher (1914, p. 533) stated that it was " a minor pest of cholam and tenai, not occurring in large numbers as a rule." Uvarov (1928, p. 317) wrote " the bionomics and even economic importance of *H. nigrorepletus* cannot be very definitely established owing to the confusion of records." As recently as 1940, Rao and Cherian remarked that its life-history was unknown.

From the available records, *H. nigrorepletus* may be regarded as a minor pest of millets (cholam or jowar), *Andropogon sorghum;* bajra, *Pennisetum typhoideum*†; tenai or Italian millet (*Setaria italica*)), rice (*Oryza sativa*), maize (*Zea mays*), hemp (*Cannabis sativa*) and sugar-cane (*Saccharum officinarum*).

Life-history.

In view of the paucity and confusion of records, the following observations were made at Benares during 1942-1944. *H. nigrorepletus* was recorded in each of these three years heavily infesting maize, jowar, sanei or hemp and sugar-cane fields lying on the outskirts of Benares, close to Gaibi village. The fields lie close together in a small area of about three acres, which is enclosed by brick walls 10 ft. high. The damage to the crops was caused by the hoppers and adults feeding on the leaves. Each year the infestation lasted for the three monsoon months, *i.e.*, from the beginning of July until the end of September. It was heaviest in August, the period when most of the hoppers became adult.

H. nigrorepletus occurs in two forms (i) the one most commonly met with is a short-winged or micropterous form which is unable to fly; and (ii) a normal-winged or macropterous form which is comparatively rare and can fly in the normal Acridian manner. The conditions that lead to the production of the two forms are not known.

The first indication of the presence of this pest is the appearance of a large number of young green hoppers in late June or early July, *i.e.*, soon after the commencement of the rains; hoppers of all stages are abundant in late July and August. These have hatched from eggs laid in the previous autumn (August-September). The basis for this conclusion is that from October to the following June the insects are not met with at all. The eggs thus have a long developmental diapause and the incubation period lasts some 10-11 months (middle August to late June or early July of the following year), a period that covers the cold winter months as well as the hot summer ones.

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* Published with the permission of the Director, Zoological Survey of India.

† Record supplied by the Imperial Entomologist, New Delhi.

Field observations suggest that the duration of the hopper stage is about three weeks. Adults begin to appear late in July and are mature by about the middle of August when copulation and oviposition occur. Copulation occurs in the usual Acridian manner. Eggs are laid in the soil, a female laying about 20-30 eggs at a time. The egg-sculpturing and the micropylar canals have been described by Husain & Roonwal (1933).

Towards the end of August or the beginning of September the insects begin to die off, and by about the middle of September very few are to be seen. The latest record was that of a macropterous individual attracted to light on 22nd September, 1944; search next day failed to reveal the presence of other individuals in the fields.*

The life-history may be summed up as follows:—

Hatching: Late June or early July, *i.e.,* the commencement of the rains.

Hoppers: Development probably takes about three weeks. Young hoppers are found in late June and early July. Older stages are common in August. Hardly any found in September.

Adults: First seen about late July. Very common in August. Mature in middle August. Die off by the end of September.

Copulation and Oviposition: Mostly about middle August to early September.

Incubation Period: Middle August to late June or early July of the following year, *i.e.*, about 10-11 months. Eggs undergo a long developmental diapause during which they overwinter and oversummer.

Natural Enemies.

A few Rollers or Blue Jays, *Coracias benghalensis benghalensis* (L.) were seen feeding on the adult grasshoppers. They were not seen to catch hoppers which, owing to their green protective coloration, evidently escape detection. Jungle Crows, *Corvus macrorhynchos,* Wagler, were observed feeding on the grasshoppers in 1943, but were not in evidence in 1944.

Control.

Control measures were not undertaken. Two points, however, are worth mentioning. It was noticed during the years under observation that ploughing and flooding had no appreciable effect in reducing the infestation.

Infested fields, after the crops had been harvested, were ploughed each September to prepare the fields for the winter crops. Though this operation must have exposed and destroyed many eggs laid in the soil, many more probably escaped destruction, so that it had no appreciable effect in reducing the following year's infestation. The ploughing, however, was rather shallow.

Similarly, late and unusually heavy rains in late September, 1943, after the crops had been harvested, kept the fields under water for several days. Yet the infestation in 1944 was no less heavy, showing that flooding did not destroy all or even the majority of the eggs.

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* Fletcher (1920, p. 309) recorded it on rice at Lonavla (Poona District, Bombay Presidency) on 21st November, 1905. This suggests that in South India, owing to the mild winters, the seasonal life-history may be somewhat different from that at Benares.

In both cases the possibility of outside infestation was ruled out for two reasons: the fields are walled in as mentioned above, and the majority of the adult grasshoppers are micropterous and are thus incapable of flight.

References.

Bolivar, I. (1912). Trab Mus. Cienc. nat. Madrid, no. 6, pp. 54, 56-59.

Coleman, L. C. (1914). New species of Indian grasshoppers belonging to the genus *Hieroglyphus* Krauss and the genus *Hierococcyx* Bolivar.—J. Bombay nat. Hist. Soc., **23**, pp. 172-175.

Fletcher, T. B. (1914). Some South Indian Insects.—Madras.

——. (1920). Annotated list of Indian crop-pests.—Proc. 3rd ent. Mtgs. Pusa 1919, **1**, pp. 33-314.

Husain, M. A. & Roonwal, M. L. (1933). Studies in *Schistocerca gregaria* Forsk. I. The micropyle in *Schistocerca gregaria* Forsk. and some other Acrididae.—Indian J. agric. Sci., **3**, pp. 639-645.

Rao, Y. R. & Cherian, M. C. (1940). Control of the rice grasshoppers. I, II.—Indian Fmg, **1**, pp. 433-436, 495-498.

Uvarov, B P. (1922). Rice grasshoppers of the genus *Hieroglyphus* and their nearest allies.—Bull. ent. Res., **13**, pp. 225-241.

——. (1928). Locusts and Grasshoppers.—London.

BIOCHEMICAL DIFFERENCES BETWEEN THE SOLITARY AND GREGARIOUS PHASES OF LOCUSTS AND NOCTUIDS.*

By J. J. MATTHÉE, B.Sc.

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Introduction.

The theory of phases, Uvarov (1921), had the object of explaining the inter-relationship between different forms of *Locusta migratoria* and *Locustana pardalina.* This theory has been accepted by most entomologists working on locust problems. Authors such as Faure (1923 and 1932), Johnston and Maxwell-Darling (1931) and later a series of others including Hussein and Ramchandra Rao, proved and confirmed the truth of Uvarov's theory.

At one time locusts were considered to be more or less monomorphic, but the phase theory changed this conception. Now they are looked upon as polymorphic insects, because certain characteristics, such as the colour pattern of the hoppers and the structure of the pronotum and relative length of the wings and hind legs of adults, differ strikingly in the phases *solitaria* and *gregaria.*

The general type of hopper found in a dense crowd shows a characteristic colour pattern: a basic black background with orange-yellow markings. The adults are characterised by having longer wings and shorter or more compressed pronota. The isolated or solitary forms show a greater variation in the colour pattern of the hoppers, which varies from green to grey-blackish, but the black and orange pattern of the swarm type is never found. The adults of these solitary forms generally have relatively short wings and the pronotum, especially in *Locusta migratoria,* is larger and much more convex in the lateral aspect.

Apart from morphological differences, others of a biological and physiological nature have also been discovered between the phases *solitaria* and *gregaria* of swarming locusts. These include the duration of the developmental period, the number of generations a year and the number of moults. Smit (1939) showed that the hoppers of the solitary phase of *Locustana pardalina* take 25 days to reach the adult stage, whereas those of *gregaria* take 40. He also stated that normally there are three generations a year of the phase *solitaria,* while *gregaria* ordinarily completes only two, although in favourable years, three may occur. Physiological differences between the phases are higher body temperatures (Strelnikov, 1936) and higher oxygen consumption (Butler & Innes, 1936), in *gregaria.*

Faure proved, by means of a series of rearing experiments, that the phase theory is also applicable to certain Lepidoptera in two recent publications, one on the lesser-army worm (*Laphygma exigua* (Hübn.)) in February, 1943, and the other on the army worm (*Laphygma exempta* (Wlk.)) in November, 1943. In the latter a few notes appear on the possibility of the existence of phase variation in the lawn caterpillar (*Spodoptera abyssinia* Guen.) where it was said: "It is rather problematical whether one would be justified in describing this variation of the larvae of *Spodoptera abyssinia* as phase variation comparable with that of locusts and army worms." The colour variation of the larvae of *S. abyssinia* as found by Faure (1943b) is less striking than that found in the case of *exempta,* where the larvae reared in crowds developed a uniform velvety black background colour in the advanced instars, whilst in those reared in isolation the colour scheme varied from green to dark brown. A small percentage of typical *gregaria* larvae was also found in the isolations.

Since there is a very distinct difference between the phases *gregaria* and *solitaria* of swarming locusts and army worms in the coloration of the hoppers and larvae, and since biological and physiological differences have been found between the two phases of locusts, one would be inclined to suspect other physiological and biochemical differences. In view of the obvious difference in activity between the two phases, *gregaria* being more active than *solitaria,* one might expect some biochemical differences as a result of physiological processes.

In the experimental work discussed in this paper, special attention was given to biochemical analyses of material referable to the two phases. Determinations were made of lactic acid and uric acid content, of hydrogen-ion concentration and of moisture and fat content, in order to ascertain whether any differences existed between the phases *solitaria* and *gregaria*. As previously mentioned, *gregaria* is more active than *solitaria,* and one would expect, as in the case of vertebrates, a higher production of lactic acid in the more active phase.

Uric acid is by far the most important nitrogenous constituent in the urine of insects, as it is in birds and reptiles. In the silkworm 85.8 per cent. of the nitrogen is excreted as uric acid (Farkas, 1903). Uric acid also predominates in the excreta of *Melanoplus* where 3.2 to 4.7 milligram per cent. of the dry excreta consists of uric acid (Brown, 1937). Owing to the difference in activity between the two phases, one would expect a similar difference in metabolism to be reflected, in all probability, in the total production of waste products. As most of the nitrogen is excreted as uric acid, determinations of the uric acid concentration in the blood of the *solitaria* and *gregaria* phases, would show whether there is a difference in content.

In view of a possible higher concentration of lactic acid in the *gregaria* phase and a possible difference in the production of waste products, of which urea, uric acid and amino acids are the most important, the hydrogen-ion concentration of the blood of the *solitaria* and *gregaria* phases was determined.

A higher rate of metabolism has been demonstrated by Butler and Innes in the phase *gregaria*. This would most probably also result in a higher consumption of food in that phase, and could possibly be correlated with a higher production of fat. As the proportion of water in insects is influenced to some extent by the quantity of fat present (Theodor, 1936), it was decided to determine both the water and fat content of the phases *solitaria* and *gregaria*.

Four species of insects were reared in the laboratory and out-of-doors for the above-mentioned analyses:—The Brown Locust (*Locustana pardalina* (Wlk.)), the African Migratory Locust (*Locusta migratoria migratorioides*, R. & F.), the Army Worm (*Laphygma exempta* (Wlk.)), and the Lawn Caterpillar (*Spodoptera abyssinia,* Guen.).

Rearing Technique.

A. *Laphygma exempta* and *Spodoptera abyssinia*.

Except for the alterations discussed below, the rearing technique described by Faure (1943 b), was employed. A dry camel's-hair brush was used to transfer the isolated larvae on to fresh food instead of a wet brush. This method accelerated the process of feeding. All eggs were left in the egg-laying cages to hatch, except in cases where some of the young larvae were used for isolation. Here a number of eggs was removed from the egg-laying cages and transferred to 1 inch × 4 inch glass tubes for hatching.

All the different stages of development were kept in a constant temperature room, at about 90° F. and about 50 per cent. relative humidity, from 4 p.m. to 8 a.m. During the day, from 8 a.m. to 4 p.m., the insects were kept in the laboratory at ordinary room temperature. These regular temperature changes made it possible to obtain normal sized larvae, pupae and adults throughout the whole breeding period.

A large percentage of the larvae died of bacterial diseases in earlier attempts when they were kept in the constant temperature room and only taken out for an hour or two each day. Those reared under the conditions of alternating temperature, described above, seemed to be healthier and the mortality due to bacterial diseases was very much lower. The parallel series of *S. abyssinia* and *L. exempta* larvae, reared in crowds and in isolation, were subjected to identical conditions of temperature, humidity and light.

After the completion of one generation, the rearing tubes and large cages were thoroughly washed and left in the sun for a few hours. They were then sprayed with 95 per cent. alcohol a day or two before being used for the next generation. This treatment kept bacterial diseases down to a minimum. Young maize, 3 inches—9 inches high, was used as food during the summer months, and in winter the larvae were fed on young barley, 3 inches—12 inches high. The same food was always given to the parallel series of larvae reared in isolation and in crowds.

B. *Locustana pardalina* and *Locusta migratoria*.

These two species were reared in the laboratory, and also in cages out-of-doors. Hoppers reared in crowds and in isolation were kept in the constant temperature room used for the army worm larvae. The crowds were kept in cages made of wood and wire gauze and two types of wire gauze cages were used for rearing the hoppers in isolation. The first type, 4 inches × 4 inches × 4 inches, was made of wire gauze fitted with a wooden floor, and the second type consisted of a wire gauze cylinder, 8 inches high and 2½ inches in diameter, fitted with a floor of galvanised iron.

The same rearing cages were used for each species both out-of-doors and in the laboratory. A high percentage of the hoppers of *L. pardalina* died when reared in isolation in these cylinders owing to the heat developed in the iron floors when exposed to the sun. A covering of hessian was then erected over the cylinders, and it was found that in the following generation a very small percentage of the hoppers died as the temperature of the iron floors was approximately the same as that of the surrounding air. The crowded and isolated hoppers of *L. pardalina* were both reared in the shade of the hessian covering. Young maize and barley plants, a little older than those given to the Noctuid larvae, were given as food to the hoppers reared in the laboratory and out-of-doors.

Great difficulty was experienced in rearing sufficiently large numbers of hoppers of *L. pardalina* of the phases *solitaria* and *gregaria* in the laboratory and out-of-doors, as a very small percentage of the available eggs hatched. Third- and fourth-instar hoppers of both phases, collected on the veld, were kindly sent by rail for analysis by Mr. C. Smit, Government Entomologist, from Middelburg, Cape Province. The *solitaria* hoppers were dispatched in small cylinders 8 inches high and 2½ inches in diameter, made of wire gauze. Only one individual was put in each cage, and a number of these small cages were packed into a larger cage of wire gauze and wood. The *gregaria* hoppers were sent in a cage 10 inches × 12 inches × 24 inches, approximately 250 individuals to a cage. Although they remained on the train for one and a half days without fresh food, they arrived in very good condition.

As an experiment, a hundred third- and fourth-instar *L. pardalina* hoppers of phase *solitaria*, were sent crowded in a single cage, 10 inches × 12 inches × 24 inches, and immediately after arrival in Pretoria isolated in 8 inches × 2½ inches wire gauze cylinders. These *solitaria* hoppers were kept crowded in the same cage for about four days. This method of sending large numbers of *solitaria* hoppers by rail seemed very satisfactory although a larger percentage developed into phase *transiens* than in the case of *solitaria* hoppers sent in isolation. The *solitaria* hoppers sent crowded in the same cage and isolated after arrival in Pretoria, were kept apart from those sent isolated and the two groups analysed separately.

The parallel series of *L. pardalina* and *L. migratoria,* reared in crowds and in isolation, were subjected to identical conditions of temperature, humidity, food and light. Those reared in the laboratory were kept at about 90° F. and about 50 per cent. relative humidity.

Chemical Analyses.

Material was analysed of two species of swarming locusts, *Locustana pardalina* and *Locusta migratoria* and two species of Noctuids, *Laphygma exempta* and *Spodoptera abyssinia.*

Only material referable to the phases *solitaria* and *gregaria* was analysed, except in the case of the lactic acid determinations, in which the phase *transiens* was also included. The larvae and pupae of *L. exempta* and *S. abyssinia* classified as *transiens* were reared singly, only one larva in a tube, as in the case of those classed as *solitaria.* For each determination a minimum of three replicates was taken in all the chemical analyses discussed in this section. The highest value found in each determination will be called the " Absolute maximum value," while the average of the different absolute maxima of all the determinations of each phase will be referred to as the " Mean absolute maximum." The terms " Absolute minimum " and " Mean absolute minimum " will be related to the minimum values in the same sense. To test the significance of the differences between the means, the data of all the chemical analyses were subjected to the t-test, described by Fisher (1936).

A. Lactic Acid.

The method used in determining the lactic acid content is described by Friedemann and Craeser (1933). As oxidising agent 0.01 N potassium permanganate was employed and no use was made of filter paper. All the solutions were separated from the ground tissues and precipitates by means of a centrifuge. A standard iodine solution ± 0.005 N was used for titrating the bound bisulphite. The exact factor of the standard iodine was determined with every series of lactic acid determinations. This was done with a 0.005 N sodium thiosulphate solution. Twenty-five millilitres aliquots of the final solution were used for analysis. This method gave very good results, and a recovery of 99.02 per cent. of a standard lactic acid solution was obtained. For the rest, the method prescribed by Friedemann and Craeser for analysing lung tissue, was employed.

1. *Laphygma exempta.*

Owing to the short life-history of the army worm and the comparative ease of rearing large numbers of individuals, it was possible to make lactic acid determinations on phases *solitaria, transiens* and *gregaria.* For comparative purposes, *solitaria* and *gregaria* or *transiens* and *gregaria* material reared at the same time and under identical conditions was analysed simultaneously.

(a) *Final instar larvae.*

Larvae of the final instar of phases *solitaria, transiens* and *gregaria* were analysed. Observations on the number of larval instars showed that larvae reared in crowds passed through six instars (Hattingh, 1941), while of those isolated, it seemed according to Faure (1943b) that a certain percentage passed through five only. To avoid confusion the term " final instar larvae " will be applied to all larvae in the last larval instar. All larvae were analysed on the second day after reaching the final larval instar.

After the living larvae had been classified into groups of ten per replicate, they were cut separately into small pieces with a pair of scissors. These pieces were dropped directly into a tared weighing bottle containing 10 millilitres of N H_2SO_4. This was found to be the only practical method of obtaining all the tissues and body fluids. A fluid, probably derived from the intestine, flowed from the mouths of larvae killed in a cyanide bottle or by means of chloroform or ether and this resulted in a loss of a great part of the body contents.

After determining the weight of the material in each replicate, the material was transferred to a mortar and thoroughly ground. Subsequently the rest of the procedure described by Friedemann and Craeser (1933) was followed.

TABLE I.

The Lactic Acid Content of *solitaria, transiens* and *gregaria* Larvae of *Laphygma exempta*

Phase	History of ancestors	Milligrams of lactic acid per gram of body weight					
		Absolute max. values		Absolute min. values		Mean values	
		Wet wt.	Dry wt.	Wet wt.	Dry wt.	Wet wt.	Dry wt.
solitaria ...	1	0·2304	—	0·1829	—	0·2060	—
	2	0·3704	4·521	0·3489	4·398	0·3613	4·478
	1	0·4414	—	0·2906	—	0·3418	—
	3	0·4629	4·508	0·4527	4·409	0·4579	4·459
	8	0·3546	4·5145	0·3188	4·4035	0·3149	4·4687
transiens ...	4	0·3435	—	0·2800	—	0·3148	—
	8	0·3435	—	0·2800	—	0·3148	—
gregaria ...	2	0·2961	—	0·2429	—	0·2784	—
	5	0·3262	—	0·2718	—	0·3081	—
	4	0·5294	—	0·4829	—	0·5103	—
	6	0·5476	5·132	0·5146	4·892	0·5274	5·019
	7	0·6778	5·040	0·6513	4·843	0·6678	4·965
	8	0·4754	5·0860	0·4327	4·8675	0·4633	4·9920

1. Parents and grandparents of phase *solitaria.*
2. Parents and grandparents of phase *gregaria.*
3. Mixed parentage of *solitaria* and *gregaria.*
4. Parents *gregaria* material from field.
5. Ancestors for 3 generations *gregaria.*
6. Ancestors for 4 successive generations *gregaria.*
7. Ancestors for 8 successive generations *gregaria.*
8. General mean.

In Table I the results are given of the lactic acid content of *solitaria, transiens* and *gregaria* larvae of *Laphygma exempta.* The results are worked out on a basis of wet and dry weight in milligram lactic acid per gramme body weight. The mean lactic acid content of the solitary phase larvae varied from 0.3188 to 0.3546 milligram per gram wet weight, while that of the *transiens* and *gregaria* larvae varied between 0.2800 and 0.3435 and 0.4327 and 0.4754 respectively. The mean values found for the three phases were 0.3149 for *solitaria,* 0.3148 for *transiens* and 0.4633 for *gregaria.*

Data, worked out on the dry weight basis, were only obtained in the case of the *solitaria* and *gregaria* phases. In the former a mean value of 4.4687 milligram lactic acid per gramme body weight was found, and in the latter the corresponding mean value was 4.9920. According to the wet weight figures, a difference of 0.1484 milligram of lactic acid was found between *solitaria* and *gregaria* larvae.

Statistically a minimum difference of 0.0830 milligrams would be significant at P = 0.01. Between *transiens* and *gregaria* larvae a difference of 0.1485 milligram of lactic acid was found, which is much higher than the minimum difference of 0.0693 that would be significant at P = 0.01. No significant difference was found between *solitaria* and *transiens,* since the minimum difference of 0.1137 at P = 0.05 is much greater than the observed difference of 0.0001 milligram. On the dry weight basis a significant difference was found between *solitaria* and *gregaria* larvae in respect of their lactic acid content. The observed difference of 0.5233 milligram was greater than the minimum significant difference of 0.0781 milligram at the level of 1 per cent.

It is evident, therefore, that the difference between *solitaria* and *gregaria* and between *transiens* and *gregaria* is highly significant, both on the wet and the dry weight basis and it can be concluded that the lactic acid concentration of *gregaria* larvae is higher than that found in *solitaria* or *transiens* larvae. Observations made on the living insects indicated that *gregaria* is the more active phase. Comparing the lactic acid concentration of phase *gregaria* with that of *solitaria,* it seems, from the results obtained, as if the statement that *gregaria* is the more active phase, is correct also from a biochemical point of view.

(b) *Pupae.*

Pupae of *Laphygma exempta* were analysed three days after entering the pupal stage. Since no morphological difference is known between the pupae of phases *solitaria, transiens* and *gregaria,* the material was classified in the last larval instar. The pupae were therefore grouped into the different phases, not on the basis of pupal characteristics but according to the colour pattern of the larvae from which they were derived.

Ten pupae were used in each replicate, and each replicate consisted of an equal number of pupae derived from larvae which had been placed into different colour types, as in the case of the analyses of larvae. Here also the replicates were of a uniform nature. The same method of preparing the material was used as described for the larvae. Living material was used, and the pupae were cut up while still alive.

The results obtained in the lactic acid analyses are given in Table II. The mean acid content of the *solitaria, transiens* and *gregaria* pupae were found to be 0.7644, 0.8099 and 0.9461 milligram per gram wet body weight respectively. Between the *solitaria* and *gregaria* pupae a difference of 0.1817 milligram was found, and this difference is greater than the minimum difference of 0.0589 milligram which would be significant at P = 0.01. A significant difference was also found between *transiens* and *gregaria* where the minimum difference of 0.0937 milligram at P = 0.01 is very much smaller than the observed difference of 0.1362. No significant difference was found between *solitaria* and *transiens,* since the observed difference of 0.0455 milligram was smaller than the minimum significant difference of 0.0715 milligram at the level of 5 per cent.

On the dry weight basis the mean lactic acid contents of *solitaria, transiens* and *gregaria* were respectively 3.1450, 2.8976 and 4.2253 milligram per gram body weight. Between *solitaria* and *gregaria* the observed difference was 1.0803 milligrams, compared with the minimum significant difference of 0.7653 at P = 0.01, therefore the observed difference is highly significant. The observed difference of 1.3277 milligram between *transiens* and *gregaria,* is also highly significant in comparison with the minimum significant difference of 0.7595 at the level of 1 per cent. In contrast with the wet weight figures given in the preceding paragraph, a significant difference was found between *solitaria* and *transiens,* on the basis of the dry weight. Here, a difference of 0.2474 milligram was found, and compared with the minimum significant difference of 0.1046 at P = 0.01, the former was much greater.

TABLE II.

The Lactic Acid Content of *solitaria, transiens* and *gregaria* Pupae of *Laphygma exempta.*

Phase	History of ancestors	Milligrams of lactic acid per gram body weight					
		Absolute max. values		Absolute min. values		Mean values	
		Wet wt.	Dry wt.	Wet wt.	Dry wt.	Wet wt.	Dry wt.
solitaria ...	1	0·7064	—	0·7050	—	0·7055	—
	2	0·8170	3·2470	0·7836	3·1150	0·7912	3·1450
	3	0·8942	—	0·6776	—	0·7671	—
	9	0·8059	3·2470	0·7221	3·1150	0·7644	3·1450
transiens ...	1	0·7446	—	0·7436	—	0·7439	—
	2	0·8748	—	0·7599	—	0·8499	—
	4	0·8265	2·9830	0·7780	2·8060	0·8030	2·8976
	9	0·8153	2·9830	0·7605	2·8060	0·8099	2·8976
gregaria ...	5	0·8618	—	0·7834	—	0·8226	—
	5	0·9561	—	0·8052	—	0·8756	—
	6	1·1540	—	0·9573	—	1·0479	—
	7	1·0670	—	0·9742	—	1·0176	—
	4	0·8778	3·4060	0·8405	3·2620	0·8653	3·3580
	8	0·8904	5·1500	0·8614	4·9770	0·8809	5·0930
	9	0·9678	4·2780	0·8737	4·1195	0·9461	4·2253

1. Parents *gregaria* material from field.
2. Mixed parentage.
3. Parents *solitaria.* Grandparents *gregaria.*
4. Ancestors for 3 successive generations as *gregaria.*
5. Parentage unknown.
6. Parents *solitaria.* Grandparents *gregaria* from field.
7. Parents and grandparents *gregaria.*
8. Ancestors for 6 successive generations *gregaria.*
9. General mean.

Significant differences were therefore found between *gregaria* and *solitaria* and between *gregaria* and *transiens,* both on the wet and the dry weight basis. In both cases *gregaria* had a higher lactic acid concentration than *solitaria* or *transiens.* The results correspond with those found in *L. exempta* larvae in the sense that the pupae originating from the most active larvae show a higher concentration of lactic acid in the whole body than the less active phase *solitaria.* The concentration in *L. exempta* pupae is comparable, quantitatively, with that of the larvae in that *gregaria* has a higher concentration than *solitaria* or *transiens.*

2. *Spodoptera abyssinia.*

The material used in the following analyses was reared in the laboratory and the parallel series of larvae reared in crowds and in isolation were subjected to identical conditions as stated on page 345.

(a) *Final instar larvae.*

Only phases *solitaria* and *gregaria* were analysed in this case, and no *transiens* material was used. The larvae were classified into their corresponding phases 24 hours after reaching the final instar. Ten larvae were used per replicate, and the different replicates of the same series were of a uniform composition, as in the case of *L. exempta.* The method of preparing the material was the same as that employed for *L. exempta* larvae.

TABLE III.

The Lactic Acid Content of *solitaria* and *gregaria* Larvae of *Spodoptera abyssinia*.

Phase	History of ancestors	Milligrams of lactic acid per gram body weight					
		Absolute max. values		Absolute min. values		Mean values	
		Wet wt.	Dry wt.	Wet wt.	Dry wt.	Wet wt.	Dry wt.
solitaria ...	1	0·1723	1·3090	0·1410	1·0710	0·1551	1·1780
	2	0·1787	1·6300	0·1276	1·1650	0·1529	1·3950
	3	0·1755	1·4695	0·1343	1·1180	0·1541	1·2865
gregaria ...	1	0·2128	1·8180	0·1750	1·4810	0·2005	1·7050
	2	0·2895	2·5480	0·2145	1·8890	0·2398	2·1110
	3	0·2512	2·1830	0·1948	1·6850	0·2202	1·9085

1. Parents mixed population collected in field.
2. Parents *gregaria*. Grandparents from field.
3. General mean.

A summary of the results obtained is given in Table III. The mean lactic acid concentration of the *solitaria* and *gregaria* larvae of *S. abyssinia* was 0.1541 and 0.2202 milligrams per gram wet body weight, and 1.2865 and 1.9085 per gram dry body weight, respectively. A difference of 0.0661 milligram was found between *solitaria* and *gregaria* larvae on the wet weight basis. Statistically, a minimum difference of 0.0338 would be significant at $P = 0.01$. A difference of 0.6220 milligram was observed between *solitaria* and *gregaria* on the dry weight basis, and this difference is much greater than the minimum significant difference of 0.4679 at the level of 1 per cent. Both on the wet and the dry weight basis, significant differences were therefore found between *solitaria* and *gregaria*, and in both instances *gregaria* yielded a higher lactic acid concentration than *solitaria*.

The same conclusions can be drawn as in the case of *L. exempta* larvae, namely, that the more active phase *gregaria* has a higher lactic acid concentration than the practically inactive solitary phase. Observations showed that the larvae of the *gregaria* phase are somewhat more active than those of the solitary phase. Crowds of *S. abyssinia* were kept under continuous observation, and it was noticed that the larvae of the first to the fourth instars were very much more active than those kept in isolation and about as active as the same instars of *L. exempta gregaria* larvae. In the fifth and sixth instars the *gregaria* larvae in the crowds of *S. abyssinia* became less active and sometimes they hardly crawled about, but even then they remained more active than the *solitaria* larvae reared in isolation. The above analyses prove biochemically that the *gregaria* larvae of *S. abyssinia* are more active than the *solitaria* larvae.

(b) *Pupae.*

A high mortality in the prepupal stage made it impossible to obtain sufficient pupae for analysis.

3. *Locusta migratoria.*

The material used in the following determinations was reared in the laboratory and out-of-doors. *Solitaria* and *gregaria* fifth-instar hoppers were analysed. The hoppers were classified into phases on the basis of the colour pattern of the fifth instar as shown on the coloured plate XVII (Faure, 1932). Hoppers reared under the same conditions were compared with one another. Thus *solitaria* and *gregaria* hoppers reared in the laboratory were considered as comparable, while those reared out-of-doors were taken as a separate group in comparing the lactic acid concentration of the two phases.

Each replicate consisted of ten fifth-instar hoppers, and the analyses were made about five days after moulting. All the hoppers used in the replicates of each determination had approximately the same colour pattern.

In the first two series of determinations, hoppers reared in isolation were taken out of their cages and transferred to a larger cage. Ten *solitaria* hoppers were put in each cage and left for half an hour before being cut up. These hoppers were active, and determinations made on them showed no difference in lactic acid content between the two phases. In view of the results obtained in the case of *Laphygma exempta* and *Spodoptera abyssinia* larvae, where *gregaria* yielded a higher lactic acid concentration than *solitaria,* it was thought advisable to change the method of transferring hoppers reared in isolation to the laboratory by keeping them in their normal state of inactivity until they were to be cut up. This was done by mincing the living hoppers immediately after removal from the isolation cages, without first crowding the ten *solitaria* hoppers into one cage. This procedure reduced the period of activity to about thirty seconds.

In all other respects the same method was used as that described for *Laphygma exempta* larvae.

TABLE IV.

The Lactic Acid Content of *solitaria* and *gregaria* fifth-instar Hoppers of *Locusta migratoria.*

Phase	Reared	History of ancestors	Milligrams of lactic acid per gram of body weight					
			Absolute max. values		Absolute min. values		Mean values	
			Wet wt.	Dry wt.	Wet wt.	Dry wt.	Wet wt.	Dry wt.
*solitaria**	Laboratory	1	0·3169	1·2550	0·2423	0·9590	0·2962	1·1729
		2	0·3139	1·2134	0·3059	1·1824	0·3108	1·2013
	Out-of-doors	3	0·3114	—	0·3010	—	0·3074	—
		7	0·3107	1·2342	0·2831	1·0707	0·3036	1·1842
gregaria	Laboratory	4	0·3357	1·3988	0·2706	1·1275	0·2917	1·2153
		5	0·3134	1·1607	0·3112	1·1527	0·3123	1·1567
	Out-of-doors	5	0·3088	—	0·3021	—	0·3063	—
		7	0·3193	1·2797	0·2946	1·1401	0·3018	1·1919
solitaria†	Laboratory	6	0·3032	—	0·2988	—	0·3017	—
		1	0·3075	—	0·2968	—	0·3039	—
		7	0·3053	—	0·2978	—	0·3028	—

* Hoppers killed immediately after removal from isolation cages.

† Hoppers after removal from isolation cages, kept in a crowd for 30 mins. before being analysed.

1. Parents *solitaria.* Grandparents *transiens.*
2. Parents and grandparents *solitaria.*
3. Parents *solitaria.* Grandparents *gregaria.*
4. Parents *gregaria.* Grandparents *transiens.*
5. Parents and grandparents *gregaria.*
6. Parents and grandparents *transiens.*
7. General mean.

A summary of the results is presented in Table IV. According to these figures the mean concentration found in the *solitaria* and *gregaria* hoppers of *Locusta migratoria* was: *solitaria* 0.3036 and *gregaria* 0.3018 milligrams per gram wet body weight. On the dry weight basis *solitaria* had 1.1842 and *gregaria* 1.1919 milligrams per gram body weight. In these cases, the *solitaria* hoppers were killed immediately after removal from the isolation cages. Both on the wet and the dry weight basis, no significant difference was found between *solitaria* and *gregaria* hoppers in respect of their lactic acid concentration. The observed differences of 0.0018 and 0.0077 milligram between the mean wet and dry weight figures respectively, are smaller than the minimum significant differences of 0.0067 and 0.0643 milligram at $P = 0.05$.

Comparing the lactic acid content of the *solitaria* hoppers killed immediately after removal from the isolation cages with those *solitaria* hoppers kept in a crowd for 30 minutes before being analysed, a difference of 0.0008 milligram was found between the wet weight figures. This difference is not significant, since the minimum significant difference of 0.0060 at a level of 5 per cent. is much greater than the observed difference. No difference was found between the *solitaria* and *gregaria* hoppers reared in the laboratory and those reared out-of-doors.

As in the case of *Laphygma exempta* and *Spodoptera abyssinia*, one would expect a higher lactic acid concentration in phase *gregaria*. From Table IV it is clear that this is not the case with *Locusta migratoria*.

A possible explanation of this unexpected result is based on the fact that the isolated *solitaria* hoppers jump about vigorously in the isolation cages before they can be caught. During this period of activity, which does not exceed thirty seconds, a lactic acid concentration may be built up in the body of the hoppers causing the content to rise to the same level as that found in the *gregaria* hoppers.

To eliminate this active jumping of the *solitaria* hoppers before they are analysed, it would be necessary to kill the inactive hopper immediately. This would be very difficult to carry out as chloroform, ether or hydrocyanic acid stimulate them, with the result that they jump actively for about a minute before they die. No improvement is likely to be obtained by using one of the above-mentioned chemicals. On the other hand, such substances will probably affect the actual lactic acid content, giving incorrect results. It seems that the only possible way of killing these *solitaria* hoppers would be by means of some quick mechanical method.

4. *Locustana pardalina.*

Owing to the difficulty experienced in rearing large numbers of *L. pardalina* hoppers in the laboratory and out-of-doors in Pretoria, it was necessary to analyse field material, but some material, reared in the laboratory, was also included in these experiments. Only fifth-instar hoppers were used.

The classification of the material into the different phases was based on the colour pattern of the fifth-instar hoppers. (See colour plate No. XIV, Faure 1932.) Determinations were made on phases *solitaria* and *gregaria* only. As in the case of *L. migratoria*, hoppers of these phases reared under identical conditions were analysed on the same day, in order to obtain comparable results. The same procedure was followed as in the case of *L. migratoria*, except that in all cases the solitary hoppers were immediately cut into small pieces after being removed from their isolation cages.

TABLE V.

The Lactic Acid Content of *solitaria* and *gregaria* fifth-instar Hoppers of *Locustana pardalina*

Phase	Ser.	History of ancestors	Milligrams of lactic acid per gram body weight					
			Absolute max. values		Absolute min. values		Mean values	
			Wet wt.	Dry wt.	Wet wt.	Dry wt.	Wet wt.	Dry wt.
solitaria ...	A	1 5	0·5439	—	0·5424	—	0·5431	—
	B	2	0·5980	2·6270	0·5414	2·3790	0·5697	2·5030
	C	2	0·5765	2·6020	0·5588	2·5230	0·5677	2·5625
		6	0·5728	2·6145	0·5475	2·4510	0·5602	2·5328
gregaria ...	D	3 5	0·5595	2·2330	0·5162	2·0610	0·5450	2·1758
	E	4	0·5588	2·2300	0·5373	2·1450	0·5406	2·1753
		6	0·5591	2·2315	0·5268	2·1030	0·5450	2·1755

1. Ancestors mixed *solitaria, transiens* and *gregaria.*
2. Parents mixed *transiens* and *gregaria* from Middelburg, C.P.
3. Parents mixed *solitaria, transiens* and *gregaria.*
4. Parents mixed *transiens* and *gregaria* from Prieska, C.P.
5. Reared in laboratory.
6. General mean.

A summary of the results of the analyses is given in Table V. The mean lactic acid concentration of the *solitaria* and *gregaria* phase hoppers was found to be 0.5602 and 0.5450 milligrams per gram wet body weight. No difference was found between the two phases since the minimum significant difference of 0.0171 at $P = 0.05$ is greater than the observed difference of 0.0152 milligram. On the dry weight basis, the *solitaria* and *gregaria* phases had a mean concentration of 2.5328 and 2.1755 milligram lactic acid per gram body weight, and this difference was found to be statistically significant. In this case the observed difference was 0.3573 milligram, while the minimum difference which would be significant at the level of 5 per cent. is 0.0875.

No difference in lactic acid content was found between *solitaria* hoppers reared in the laboratory (Table V, series A), and those collected in the field (Table V, series B and C). The same applies for *gregaria* hoppers reared in the laboratory (Table V, series D), and those sent from the field (Table V, series E).

The analyses of *solitaria* hoppers sent from Middelburg, Cape Province, crowded in a single cage and isolated after arrival in Pretoria, were also compared with the results obtained by analysing *solitaria* hoppers sent isolated, one individual in each small cage (Table V, series B and C). In this case no difference was found between the *solitaria* hoppers of both series. The former gave a lactic acid concentration of 0.5697 milligram lactic acid per gram wet weight while the latter had a concentration of 0.5677 milligram per gram wet weight.

TABLE VI.

The Lactic Acid Content of the Phases of the four Species of Insects analysed
(*Laphygma exempta*, *Spodoptera abyssinia*, *Locusta migratoria* and *Locustana pardalina*).

Species and stage	Phase	Milligrams of lactic acid per gram body weight					
		Mean absolute max. values		Mean absolute min. values		General mean values	
		Dry wt.	Wet wt.	Dry wt.	Wet wt.	Dry wt.	Wet wt.
L. exempta larvae	*solitaria*	4·5145	0·3546	4·4035	0·3188	4·4687	0·3149
	transiens	—	0·3435	—	0·2800	—	0·3148
	gregaria	5·0860	0·4754	4·8675	0·4327	4·9920	0·4633
L. exempta pupae	*solitaria*	3·2470	0·8059	3·1150	0·7221	3·1450	0·7644
	transiens	2·9830	0·8153	2·8060	0·7605	2·8976	0·8099
	gregaria	4·2780	0·9678	4·1195	0·8737	4·2253	0·9461
S. abyssinia larvae	*solitaria*	1·4695	0·1755	1·1180	0·1343	1·2865	0·1541
	gregaria	2·1830	0·2512	1·6850	0·1948	1·9085	0·2202
L. migratoria, fifth-instar hoppers	*solitaria*	1·2342	0·3107	1·0707	0·2831	1·1842	0·3036
	gregaria	1·2797	0·3193	1·1401	0·2946	1·1919	0·3018
L. pardalina, fifth-instar hoppers	*solitaria*	2·6145	0·5728	2·4510	0·5475	2·5328	0·5602
	gregaria	2·2315	0·5591	2·1030	0·5268	2·1755	0·5450

5. *Summary and discussion: lactic acid.*

A summary of the mean lactic acid concentration found in the four species analysed is given in Table VI. On the wet weight basis the mean absolute minimum value of 0.1343 was found in the *solitaria* larvae of *Spodoptera abyssinia,* while the mean absolute maximum value of 0.9678 was found in the *gregaria* pupae of *L. exempta.* The mean values for the four species of insects analysed varied between 0.1541 in the *solitaria* larvae of *S. abyssinia* and 0.9461 in the *gregaria* pupae of *L. exempta.*

A marked difference was found between the larvae and pupae of phases *solitaria* and *gregaria* of the two species of Noctuids analysed. The phase *gregaria* showed a higher concentration than *solitaria.*

No significant difference was found between the lactic acid concentration of fifth-instar hoppers of *solitaria* and *gregaria* of the two species of swarming locusts analysed, except in the case of *L. pardalina,* where a significant difference was found between the content of the two phases worked out on a dry weight basis with the *solitaria* phase showing a higher concentration than the *gregaria* phase.

The larvae of the two phases of *L. exempta* showed a higher lactic acid concentration than the larvae of *S. abyssinia.* It seems as if *L. exempta* larvae are more active in the final instar than those of *S. abyssinia* in both phases, on the assumption that the more active individual will produce the largest amount of lactic acid. This tentative conclusion corresponds with general observations made on the activity of the larvae of the two species. In handling the larvae of these two species it is obvious that both phases of *L. exempta* are more active than those of *S. abyssinia.* This difference in activity was also reported by Faure (1943 b).

The fifth-instar hoppers of *L. pardalina* gave a higher lactic acid concentration than those of *L. migratoria.* Whether this difference is due to a higher activity of *L. pardalina* hoppers is difficult to say. This may probably be the case, but no direct observations were made on the relative activity of the hoppers of these two species.

A difference in lactic acid content was found to exist between phases *solitaria* and *gregaria* of *L. exempta* and *S. abyssinia.* The *gregaria* phase showed a higher concentration than *solitaria.* On the other hand no difference was found between the two phases of *L. migratoria* and *L. pardalina,* worked out on the wet weight basis. Comparing the results of the two insect groups with one another, there seems to be something faulty. The solitary phase larvae of the two Noctuids which were reared in glass tubes, 4 in. × 1 in., could be kept in their normal state of inactivity until they were killed. The isolated larvae of these two Noctuids were very inactive, and if taken out of the tubes they did not crawl about. They could therefore be removed from the rearing tubes without disturbing them. On the other hand it was impossible to keep the *solitaria* hoppers of the two swarming locusts in their normal state of inactivity during handling. Owing to the type of isolation cages and the tendency of the hoppers to jump about when disturbed, it took at least thirty seconds to remove an isolated hopper from its cage, and this resulting activity will naturally result in an increase in the concentration of lactic acid.

The results suggest that a minimum of thirty seconds of active jumping will cause a rise in the lactic acid concentration in the body of the *solitaria* hoppers, bringing it up to the same level as that found in the *gregaria* hoppers.

In the thorax of the dragon-fly *Aeschna* during rest, the lactic acid amounts to 0.283 per cent. of the wet weight, while after stimulation it is increased to 0.373 per cent. (Schütze, 1932). Similarly an increase in lactic acid concentration can also be expected in the case of *solitaria* hoppers, which jump vigorously before being killed. It may be on this account that no difference was found between the *solitaria* and *gregaria* phases of *L. migratoria* and to a certain extent of *L. pardalina*. In the latter no difference was found between the two phases on a wet weight basis, but *solitaria* showed a higher lactic acid concentration than *gregaria* on the dry weight basis.

B. URIC ACID.

The uric acid content of the blood of the same four species of insects was determined. The haemolymph of the *gregaria* and *solitaria* phases of each species was used. Folin's (1933 and 1934) direct method was adopted to determine the uric acid content. Only deprotenised unlaked blood was used as this gave truer values. The colour comparison between the standard uric acid solution and the unknown tungstic acid blood filtrate was made by means of a photoelectric colorimeter.

Lithium oxalate, which was necessary to make up the urea-cyanide solution, was unobtainable at the time of the experiments, and it had to be prepared in the laboratory. A very good product was obtained by neutralising a lithium hydroxide solution with oxalic acid. The method as finally used gave a 99.7 per cent. recovery of a uric acid solution of known concentration.

1. *Laphygma exempta.*

The haemolymph of the final instar larvae of phases *solitaria* and *gregaria* of this species was used for analysis. The replicates of each series, as in the case of the lactic acid determinations, contained a uniform population of *gregaria* and *solitaria* phase individuals respectively. In all cases the larvae were fed on young maize.

As the larvae contained only two to three drops of blood per larva, it was necessary to devise a method giving as much blood as possible from each individual. It was considered desirable to use only the body-fluid (haemolymph) for determining the uric acid content, and to exclude the contents of the alimentary canal. After several methods had been tried, the blood was drained off from the larvae in the following way:—The larvae, still alive, were held in position with a pair of forceps over a 15 cc. centrifuge tube containing a few drops of paraffin oil, which served as a protecting layer to prevent the blood from being oxidised by the air. The body wall was punctured with a pair of sharp pointed scissors, and the blood allowed to drain out into the centrifuge tube. The first few drops came out quite freely but the last vestiges had to be squeezed out, by applying a very light pressure on the body of the larvae with another pair of forceps. Subsequent dissections showed that the alimentary canal remained undamaged and no stomach juices were obtained in the haemolymph.

The results obtained with the final instar larvae are given in Table VII. The mean uric acid content of the blood varied between 50.68 and 51.64 milligrams per cent. in the solitary phase, while in *gregaria* it varied between 46.09 and 47.97. A difference of 4.20 milligrams per cent. was found between the average content of phases *solitaria* and *gregaria*, and this difference, which is greater than the minimum significant difference of 2.53 milligram at $P = 0.01$, was statistically significant. The blood of *solitaria* therefore had a higher uric acid concentration than that of *gregaria*.

2. *Spodoptera abyssinia.*

The blood of final instar larvae of both phases, which were fed on young maize, was used for determining the uric acid concentration. In all respects the same method was employed in obtaining and preparing the blood for analysis as described for *exempta* larvae. The results are given in table VII. The mean uric

TABLE VII.

The Uric Acid Content of the Blood of final instar Larvae of Phases *solitaria* and *gregaria* of *Laphygma exempta* and *Spodoptera abyssinia*.

Species	Phase	History of ancestors	Milligrams per cent. uric acid		
			Absolute min. values	Absolute max. values	Mean values
L. exempta ...	*solitaria* ...	1	51·20	53·60	52·30
		1	51·50	52·80	52·10
		1	50·00	50·09	50·06
		1	50·00	50·09	50·03
		5	50·68	51·64	51·11
	gregaria ...	1	49·60	50·40	49·90
		1	48·80	51·20	50·10
		1	45·45	48·45	46·45
		1	45·45	46·36	46·06
		1	41·41	43·42	42·03
		5	46·09	47·97	46·91
S. abyssinia ...	*solitaria* ...	2	20·00	20·00	20·00
		3	20·00	21·05	20·52
		5	20·00	20·53	20·17
	gregaria ...	2	12·63	13·68	13·33
		4	14·74	15·26	14·58
		5	13·68	14·47	14·12

1. Parents and grandparents *gregaria*.
2. Parents mixed *gregaria* and *transiens*.
3. Parents *solitaria*. Grandparents mixed *gregaria* and *transiens* from field.
4. Parents *gregaria*. Grandparents mixed *gregaria* and *transiens* from field.
5. General mean.

acid content of the blood of the *solitaria* larvae varied from 20.00 to 20.53 milligrams per cent. with a general mean value of 20.17, while that of *gregaria* varied from 13.68 to 14.47, with a general mean value of 14.12 milligrams per cent. Between these two phases there is a difference of 6.05 milligrams per cent. which is greater than the minimum difference of 1.37 the signficant figure at P. = 0.01. It is evident that a statistically significant difference was found in the uric acid content of the blood of the phases *solitaria* and *gregaria*. The blood of *solitaria* contained a higher concentration of uric acid than that of *gregaria*.

3. *Locusta migratoria*.

The blood of fifth-instar hoppers of phases *solitaria* and *gregaria* was used. All replicates consisted of uniform individuals of the same age. The blood of all the hoppers of both phases was drained five days after the hoppers had moulted. All hoppers were fed on young maize.

In draining the blood from the bodies of the hoppers, a special method of obtaining the haemolymph only, without getting it mixed with the contents of the alimentary canal or other body juices, was adopted.

As in the case of the larvae of *L. exempta* and *S. abyssinia*, a 15 cc. centrifuge tube containing a few drops of paraffin oil was used to drop the blood into. The hopper was held between the fingers; the mesothoracic leg was cut off about $\frac{1}{8}$ of an inch from the body, and the blood was allowed to flow out of the stump. By applying light pressure to the body with the fingers all the available blood was obtained.

Subsequent dissection showed that the alimentary canal remained intact, and no stomach juices were mixed with the haemolymph. The hoppers of both phases were fed on maize.

The results obtained in the analyses of the blood of the fifth-instar hoppers of both phases are tabulated in table VIII. The mean uric acid content of the blood of the *solitaria* hoppers varied from 20.74 to 22.92, while that of the *gregaria* hoppers varied from 12.59 to 15.78 milligrams per cent. A difference of 6.86 milligrams per cent. was found between the general mean values of *solitaria* and *gregaria*, and this difference was statistically significant since a minimum dfference of 0.52 milligram per cent. would be significant at the level of one per cent. As in the previous cases the blood of *solitaria* yielded a higher concentration of uric acid than that of *gregaria*.

4. *Locustana pardalina.*

The blood of fifth-instar hoppers of both phases was analysed. In all cases young maize and grass was used as food for the hoppers. The same procedure was used for the preparation of the blood as in the case of *L. migratoria*, described above.

TABLE VIII.

The Uric Acid Content of the Blood of fifth-instar Hoppers of Phases *solitaria* and *gregaria* of *Locusta migratoria* and *Locustana pardalina.*

Species	Phase	History of ancestors	Milligram per cent. uric acid		
			Absolute min. values	Absolute max. values	Mean values
L. migratoria ...	*solitaria* ...	1	24·41	25·08	24·63
		2	18·98	19·66	19·40
		3	14·34	19·62	16·23
		4	25·33	27·33	26·45
		11	20·74	22·92	21·22
	gregaria ...	5	14·91	16·94	15·49
		6	14·48	16·28	15·55
		7	8·30	12·83	11·57
		8	12·67	14·67	13·66
		11	12·59	15·78	14·36
L. pardalina ...	*solitaria* ...	9	18·18	21·82	20·61
		9	19·09	21·82	20·00
		11	18·64	21·82	20·31
	gregaria ...	10	11·81	15·45	13·93
		10	10·91	15·45	13·63
		11	11·36	15·45	13·78

1. Ancestors for 4 successive generations phase *solitaria*.
2. Parents *gregaria*. Grandparents mixed *gregaria* and *transiens*.
3. Parents and grandparents *gregaria*.
4. Parents and grandparents *solitaria*.
5. Parents and grandparents mixed *gregaria* and *transiens*.
6. Parents *transiens*, grandparents *gregaria*.
7. Parents and grandparents *transiens*.
8. Parents *solitaria* and grandparents *transiens*.
9. Parents mixed *gregaria* and *transiens*. Field material from Middelburg, C.P.
10. Parents mixed *gregaria* and *transiens*. Field material from Prieska, C.P.
11. General mean.

The results obtained in these determinations are summarised in Table VIII. In the blood of *solitaria*, the mean uric acid content varied from 18.64 to 21.82, while in the *gregaria* hoppers it varied from 11.36 to 15.45 milligrams per cent. Between the general mean values a difference of 6.53 milligrams per cent. was found. Statistically a minimum difference of 3.34 milligrams per cent. at a level of one per cent. would be significant. Since the observed difference is very much greater than the minimum significant difference at $P = 0.01$, it can be concluded that the former is highly significant and that *solitaria* yielded a higher uric acid concentration than *gregaria*.

5. *Summary and discussion : uric acid.*

The blood of the phase *solitaria* of all four species analysed yielded a higher concentration of uric acid than that of the phase *gregaria*. This higher concentration of uric acid in phase *solitaria* is very difficult to explain, owing to our present limited knowledge of insect physiology and no explanation of this presumed abnormality will be attempted at this stage. Further experiments should be undertaken to provide data on the rate of eliminaton of uric acid from the blood by the Malpighian tubes in both phases. Determination of the uric acid content of the excreta of phases *solitaria* and *gregaria*, would throw more light on this point and possibly provide an explanation for the higher concentration of uric acid found in the blood of *solitaria*.

There seems to be no marked difference between the uric acid concentration of phases *solitaria* and *gregaria* in the three species *L. migratoria*, *L. pardalina* and *S. abyssinia*. In all three cases the content of phase *solitaria* varied from 20.17 milligrams per cent. to 21.22 milligrams per cent., and in phase *gregaria* from 13.78 to 14.36 milligrams per cent. On the other hand, the uric acid concentration of both phases of *L. exempta* is more than twice as high as that of the three other species. *L. exempta* seems to have an almost abnormally high concentration of uric acid. The mean content of the blood of final instar larvae varied from 46.91 milligrams per cent. in *gregaria* to 51.11 milligrams per cent. in *solitaria*.

Babers (1938) analysed the blood of sixth-instar larvae of the Southern army worm (*Prodenia eridania*). He found a concentration of 14.8 milligrams per cent. uric acid which he described as high, but he adds, "This is to be expected, since it has been shown that insects excrete most of their waste nitrogen in the form of uric acid." The blood of *L. exempta* final instar larvae contains even more uric acid than the Southern army worm as has been shown, but it is difficult to say what accounts for this high concentration.

C. FAT ANALYSES.

Analyses were made to determine the percentage of fat in the final instar larvae of phases *solitaria* and *gregaria* of *L. exempta* and *S. abyssinia* and also of the fifth-instar hoppers of *L. migratoria* and *L. pardalina*. The fat was extracted by means of ethyl ether and weighed after the evaporation of the ether from the ether-fat extract.

1. *Laphygma exempta : final instar larvae.*

Larvae of phases *solitaria* and *gregaria*, which had been reared under identical conditions and had received the same food, were compared with one another. All the replicates of each determination consisted of the same number of individuals showing approximately identical colour patterns. Twelve larvae were used per replicate.

The living larvae were weighed and then cut into small pieces in a petri dish by means of a pair of scissors. The body fluids were absorbed by the same cotton wool in which the harder tissues of the body had been placed. This cotton wool, containing the material, was placed in an extraction tube which was afterwards transferred to an oven at 110° C. and left for three hours until perfectly dry. The dry material was then treated with ether to extract the fat.

The results of the analyses are given in Table IX; they have been worked out both on the wet and the dry weight basis. The mean fat content of the *solitaria* larvae varied from 1.39 to 1.73 per cent. in the wet weight figures, while in the *gregaria* larvae it varied from 2.71 to 3.14 per cent. The general mean value of *solitaria* was 1.51 as compared with 2.73 per cent. in *gregaria*, a difference of 1.22 per cent. which was statistically significant, since the minimum significant difference at $P = 0.05$ is 1.04 per cent.

The mean dry weight figures for the two phases were found to be 16.87 per cent. for *solitaria* and 23.57 for *gregaria*, the difference being 6.70 per cent. Statistically a minimum difference of 4.87 per cent. would be significant at $P = 0.05$. Since the minimum difference in the fat content between *solitaria* and *gregaria* is smaller than the observed difference, it is evident that the difference between the two phases is highly significant at the level of 5 per cent. Both on the wet and the dry weight basis, *gregaria* had a higher percentage of fat than *solitaria*.

2. *Laphygma exempta : pupae.*

No food is taken in during the pupal stage, and the main source of energy is supplied by fat accumulated during the larval stage. These fats, which are stored

TABLE IX.

The Fat Content of the final instar Larvae and Pupae of Phases *solitaria* and *gregaria* of *Laphygma exempta*.

Stage	Phase	History of ancestors	Percentage of fat					
			Wet weight basis			Dry weight basis		
			Absolute min. values	Absolute max. values	Mean values	Absolute min. values	Absolute max. values	Mean values
Final instar larvae.	*solitaria*	1	1·00	1·55	1·28	12·41	19·48	16·13
		1	1·77	1·92	1·85	17·67	18·27	17·97
		8	1·39	1·73	1·51	15·04	18·87	16·87
	gregaria	2	1·82	2·66	2·16	18·44	25·87	21·63
		3	3·59	3·62	3·61	26·48	26·68	26·58
		8	2·71	3·14	2·73	22·46	26·27	23·57
Pupae ...	*solitaria*	4	7·43	8·08	7·65	27·06	28·25	27·57
		5	6·87	7·07	6·97	27·52	29·90	27·71
		8	7·15	7·57	7·37	27·29	28·07	27·61
	gregaria	6	8·88	9·19	9·02	34·83	35·20	35·00
		7	10·06	10·76	10·41	37·15	38·15	37·65
		8	9·47	9·97	9·57	35·99	36·67	36·06

1. Parents *solitaria*. Grandparents *solitaria*. Great grandparents *gregaria*
2. Parents, grandparents and great grandparents *gregaria*.
3. Ancestors for 7 generations all *gregaria*.
4. Parents and grandparents *gregaria*.
5. Parents *solitaria*. Grandparents and great grandparents *gregaria*.
6. Ancestors for 4 generations all *gregaria*.
7. Ancestors for 6 generations all *gregaria*.
8. General mean.

chiefly in the fat body, provide most of the energy for growth and metamorphosis. In the pupae of the honey bee, the fat content falls from 4.1 per cent. of the dry weight on the first day of the pupal stage to 0.9 per cent. at the end of the stage (Strauss, 1911). In this case the fat content decreased as the pupae became older. It was therefore necessary to analyse pupae of the same age, and the pupae of the *solitaria* and *gregaria* phases, used in the writer's analyses, were three days old. Each replicate consisted of thirteen pupae and all replicates, as in the case of the larvae, of an equal number of pupae whose larvae had been classified into the different colour groups. In all respects the same method of preparing the pupae for analysis was employed as that described for the larvae.

The results of the analyses are tabulated in Table IX. In the *solitaria* phase pupae 7.37 per cent. and in the *gregaria* phase 9.57 per cent. of the wet weight consisted of fat. The difference between these two phases was 2.20 which was statistically significant, since the minimum difference of 1.39 per cent. is significant at P = 0.01.

On the dry weight basis the observed difference of 8.45 per cent. between the mean fat content of the two phases was greater than the minimum significant difference of 7.12 per cent. at P = 0.01. On both the wet and the dry weight basis a significant difference in fat content was found between *solitaria* and *gregaria*. In both cases *gregaria* had a higher concentration of fat than *solitaria*.

TABLE X.

The Fat Content of the final instar Larvae and Pupae of Phases *solitaria* and *gregaria* of *Spodoptera abyssinia*.

Stage	Phase	History of ancestors	Percentage of fat					
			Wet weight basis			Dry weight basis		
			Absolute min. values	Absolute max. values	Mean values	Absolute min. values	Absolute max. values	Mean values
Final instar larvae	*solitaria*	1	2·97	3·31	3·14	27·20	30·16	28·68
		2	3·16	4·18	3·67	24·31	31·32	27·82
		5	3·06	3·74	3·12	25·75	30·74	28·36
	gregaria	3	4·00	4·24	4·12	36·26	36·58	36·42
		2	5·20	6·38	5·79	45·34	53·55	49·44
		5	4·60	5·31	4·95	40·80	45·07	42·93
Pupae ...	*solitaria*	4	5·26	6·00	5·63	20·07	22·75	21·41
		2	6·89	8·72	8·09	24·86	32·26	28·27
		5	6·07	7·36	7·11	22·47	27·51	25·59
	gregaria	3	7·74	7·93	7·83	29·23	30·34	29·78
		2	9·57	10·77	10·36	37·25	40·64	39·21
		5	8·66	9·35	9·35	33·24	35·49	35·38

1. Parents *solitaria*. Grandparents mixed *gregaria* and *transiens* from field.
2. Parents mixed *gregaria* and *transiens* from field.
3. Parents and grandparents *gregaria*.
4. Parents *solitaria* and *transiens*. Grandparents from field.
5. General mean.

3. *Spodoptera abyssinia : final instar larvae.*

The method of preparation of the material was the same as that employed for *L. exempta* larvae. Each replicate consisted of ten larvae.

The results of the analyses of the two phases are tabulated in Table X. The wet weight fat content of phase *solitaria* varied from 3.06 to 3.74 per cent.; the general mean was 3.12 per cent. In the *gregaria* phase the mean fat content varied from 4.60 to 5.31, with a general mean value of 4.95 per cent. The difference of 1.83 per cent. between the mean values of these two phases is higher than the minimum significant difference of 1.34 per cent. at P = 0.05.

On the dry weight basis the fat content varied from 25.75 to 30.74 with a mean value of 28.36 per cent. in *solitaria* and from 40.80 to 45.07, with a mean value of 42.93 per cent. in *gregaria*. The observed difference of 14.57 per cent. between the two phases is greater than the minimum significant difference of 10.41 per cent. at P = 0.05.

On both the wet and the dry weight basis a significant difference was found between the phases *solitaria* and *gregaria*. In both cases *gregaria* yielded a higher fat content than *solitaria*.

4. *Spodoptera abyssinia : pupae.*

The same procedure was employed as that used for *L. exempta* pupae. Each replicate consisted of ten pupae.

The percentage of fat found in the two phases of *S. abyssinia* pupae are given in Table X. The mean fat content of the *solitaria* and *gregaria* pupae of *S. abyssinia* was 7.11 and 9.35 per cent. of the wet weight. The difference, 2.24 per cent., is greater than the minimum significant difference of 2.20 per cent. at P = 0.05. On the dry weight basis *solitaria* had a mean fat content of 25.59 while *gregaria* yielded 35.38 per cent. The observed difference between these two mean values is 9.79 per cent. Statistically a difference of 7.39 per cent. would be significant at a level of 5 per cent.

On both the wet and the dry weight basis a significant difference in fat content was found between *solitaria* and *gregaria* pupae, the latter containing a higher percentage than the former.

5. *Locusta migratoria : fifth-instar hoppers.*

Fifth-instar hoppers were analysed about seven days after moulting. The replicates consisted of the same number of individuals classified into the various colour groups and ten hoppers were used in each replicate.

The bodies of the living hoppers were cut into small pieces and dried in an oven at 110° C. The whole insect, including legs, wing pads and other appendages was used in the determination. The fat was extracted from the dry material by means of ethyl ether.

The figures for the percentages of fat found are given in Table XI. The mean fat content of the *solitaria* hoppers varied from 2.74 to 2.95 per cent. wet weight with a general mean value of 2.83 per cent. while in the *gregaria* hoppers it varied from 3.58 to 3.76 with a general mean value of 3.56 per cent. Between these two phases the difference of 0.73 per cent. was highly significant compared with the minimum significant difference of 0.63 per cent. at the level of 1 per cent.

On the dry weight basis the fat content values varied from 10.92 to 11.37 in the *solitaria* and from 14.00 to 14.59 per cent. in the *gregaria* hoppers; the general mean values were 11.11 and 14.02 per cent. respectively. The observed difference

TABLE XI.

The Fat Content of fifth-instar Hoppers of Phases *solitaria* and *gregaria* of *Locusta migratoria* and *Locustana pardalina*.

Species	Phase	History of ancestors	Percentage of fat					
			Wet weight basis			Dry weight basis		
			Absolute min. values	Absolute max. values	Mean values	Absolute min. values	Absolute max. values	Mean values
L. migratoria	*solitaria*	1	2·57	2·85	2·73	10·52	11·01	10·83
		2	2·91	3·05	2·98	11·33	11·73	11·53
		7	2·74	2·95	2·83	10·92	11·37	11·11
	gregaria	3	3·05	3·31	3·14	12·67	13·60	13·06
		4	4·12	4·22	4·17	15·33	15·58	15·45
		7	3·58	3·76	3·56	14·00	14·59	14·02
L. pardalina	*solitaria*	5	2·81	2·89	2·85	12·39	12·63	12·51
		5	2·85	2·93	2·89	12·75	13·40	13·07
		7	2·83	2·91	2·87	12·57	13·01	12·79
	gregaria	6	3·48	3·78	3·63	14·10	15·07	14·58
		6	3·58	3·80	3·69	14·28	15·07	14·67
		7	3·53	3·79	3·66	14·19	15·07	14·63

1. Parents *solitaria*. Grandparents *gregaria*.
2. Ancestors for 3 generations all *solitaria*.
3. Parents and grandparents *gregaria*.
4. Ancestors for 3 generations all *gregaria*.
5. Parents mixed *gregaria* and *transiens*. Field material from Middelburg, C.P.
6. Parents mixed *gregaria* and *transiens*. Field material from Prieska, C.P.
7. General mean.

of 2.91 per cent. was statistically significant since it was greater than the minimum difference of 2.15 per cent. which would be significant at P=0.01.

Both on the wet and the dry weight basis, statistically significant differences in fat content were found between *solitaria* and *gregaria* hoppers of *L. migratoria*. In both cases *gregaria* had a higher percentage of fat than *solitaria*.

6. *Locustana pardalina*.

Ten fifth-instar hoppers were used per replicate, and the same method of preparing the material was used as in the case of *L. migratoria*.

The results of the fat analyses of the two phases are given in Table XI. The mean wet weight fat content of the *solitaria* hoppers varied from 2.83 to 2.91 with a general mean value of 2.87 per cent. In the *gregaria* hoppers the fat content varied from 3.53 to 3.79 with a general mean value of 3.66 per cent. This gives a difference between the general mean values of 0.79 per cent. which is statistically significant since a minimum difference of 0.29 would be significant at P=0.01.

On the dry weight basis the mean fat content of *solitaria* varied from 12.57 to 13.01 with a general mean value of 12.79 per cent. The mean percentage of fat in *gregaria* varied from 14.19 to 15.07 with a general mean value of 14.63 per cent. The observed difference of 1.84 per cent. between the two phases is statistically significant since a minimum difference of 0.95 would be significant at a level of one per cent.

The differences in fat content between *solitaria* and *gregaria* hoppers are statistically significant both on the wet and the dry weight basis. *Gregaria* hoppers had a higher percentage of fat than *solitaria.*

7. *Summary and conclusions : fat analyses.*

Statistically significant differences in fat content were found between *solitaria* and *gregaria* individuals in the four species of insects analysed. In all cases *gregaria* yielded a higher percentage of fat than the solitary phase individuals, both on the wet and the dry weight basis.

A higher rate of metabolism has been demonstrated by Butler and Innes (1936), in the phase *gregaria.* The higher rate of activity and metabolism would most probably result in a higher consumption of food in the more active phase than in *solitaria,* and could possibly be correlated with a higher production of fat.

The percentage of fat in different insects is exceedingly variable. In the mature larva of *Calliphora,* fat comprises 22 per cent. of the dry weight (Weinland, 1909), in the corpse-fly, *Ophyra cadaverina,* 41-45 per cent. (Tangl, 1909), and in *Bombyx mori* 7.1 per cent. (Farkas, 1903). In the present determinations the lowest fat content was 11.11 per cent. of the dry weight in *solitaria* fifth-instar hoppers of *L. migratoria.* The highest mean percentage of fat was found in the *gregaria* larvae of *S. abyssinia,* where 42.93 per cent. of the dry weight consisted of fat.

D. HYDROGEN-ION CONCENTRATION.

Owing to the large volume of blood required for determining the hydrogen-ion concentration, it was impossible to make determinations on all the four species and only those which could be easily reared in large numbers were used for these determinations. For this reason *gregaria* and *solitaria* individuals of *L. exempta* and *L. migratoria* were selected.

The hydrogen-ion concentration of the blood was determined electrometrically by means of a small quinhydrone electrode. Two cc. of blood were used for each determination. In order to obtain 2 cc. of blood for each replicate, large numbers of individuals were required, since the amount obtained from individual larvae was very small. For instance, each final instar-larva of *L. exempta* gave only two or three drops of blood, and about twenty larvae were required in order to obtain 2 cc.

1. *Laphygma exempta : final instar larvae.*

The method of draining the blood from the larvae was the same as that already described for the determination of uric acid. The temperature of the blood was 19°C. at the time of the determination.

The results obtained in the hydrogen-ion concentration determinations of the blood of the two phases are given in Table XII. This is only a summary table of the mean values of the original data. From these mean values it is evident that there was a marked difference between the hydrogen-ion concentration of the two phases of *L. exempta* final instar larvae. The mean pH value of *solitaria* was 8.86 while that of *gregaria* was 8.55, giving a difference of 0.31, which is significant at $P=0.05$. The blood of *solitaria,* therefore, was less acid than that of *gregaria.*

The blood of two series of *solitaria* larvae were analysed. Series A consisted of larvae having the same colour pattern as figures 6 and 7, and series B consisted of larvae identical with figure 2 of the coloured plate in the publication on the occurrence of phase variation in *L. exempta* by Faure (1943b). The blood

TABLE XII.

The Reaction of the Blood of final instar Larvae and fifth-instar Hoppers of Phases *solitaria* and *gregaria* of *Laphygma exempta* and *Locusta migratoria*.

Species	Phase	Series	History of ancestors	pH values		
				Absolute min. values	Absolute max. values	Mean values
L. exempta ...	*solitaria*	A	1	8·70	8·80	8·74
			2			
		B	3	8·90	9·10	8·98
			12	8·80	8·95	8·86
	gregaria	C	4	8·50	8·66	8·58
			5	8·49	8·55	8·51
			12	8·49	8·61	8·55
L. migratoria	*solitaria*		6	6·975	7·050	7·008
			7	6·900	6·920	6·910
			8	6·400	6·450	6·425
			12	6·758	6·807	6·814
	gregaria		9	7·050	7·100	7·060
			10	6·800	6·810	6·805
			11	6·300	6·320	6·310
			12	6·716	6·743	6·776

1. Parents *solitaria*. Grandparents *gregaria*.
2. Parents and grandparents *solitaria*.
3. Great grandparents *gregaria*.
4. Parents and grandparents *gregaria*.
5. Parents, grandparents and great grandparents *gregaria*.
6. Parents *gregaria*. Grandparents *transiens*.
7. Ancestors for 4 generations all *solitaria*.
8. Parents and grandparents *transiens*.
9. Ancestors for 3 generations all *gregaria*.
10. Ancestors for 4 generations all *gregaria*.
11. Parents *transiens*.
12. General mean.

of the darker type *solitaria* larvae (Series A) had a pH value of 8.74, while that of the paler type *solitaria* larvae (Series B) had a pH of 8.98 indicating that the blood of the paler type larvae was less acid than that of the darker type.

The blood of the two sets of *gregaria* larvae analysed (Series C) showed no significant difference. All these larvae were typical *gregaria* of the same colour pattern (see coloured plate, figure 1, Faure 1943b). A comparison of the three series, namely: *gregaria* (Series C) and the dark and pale *solitaria* types (Series A and B), seems to show that the hydrogen-ion concentration decreases as the colour intensity of the larvae decreases, the paler the colour of the larvae the less acid the blood.

The blood of both phases showed a slightly alkaline reaction, whereas Babers (1938) found a slightly acid blood with a pH value of 6.53 in the Southern army worm in America so the blood of members of the same family may show great differences in hydrogen-ion concentration.

2. *Locusta migratoria : fifth-instar hoppers.*

The same procedure as described above was followed. The amount of blood obtained from a single hopper varied from 1-6 drops, and about 10-15 hoppers were required to give 2 cc.

The results of the determinations are presented in Table XII. The average pH value of the blood of *solitaria* was 6.814 while that of *gregaria* was 6.776 giving a difference of 0.038 which was not statistically significant, since the minimum significant difference at P=0.05 was larger than the observed difference. The margin of difference is not as great as in the case of *L. exempta* larvae, but it shows the same tendency, namely a slightly greater acidity in the blood of *gregaria* as compared with that of *solitaria.*

3. *Summary: hydrogen-ion concentration.*

The blood of phase *solitaria* of *L. exempta* and *L. migratoria* is less acid than that of phase *gregaria*. The blood of *L. exempta* final instar larvae of both phases has a slight alkaline reaction, while the blood of *L. migratoria* fifth instar hoppers has a slightly acid reaction.

TABLE XIII.

The mean Water Content of Phases *solitaria* and *gregaria* of the final instar Larvae and Pupae of *L. exempta* and *S. abyssinia* and the 5th-instar Hoppers of *Locusta migratoria* and *Locustana pardalina.*

Species and stage	Phase	Mean moisture content in percentage		
		Mean absolute max. values	Mean absolute min. values	Mean values
L. exempta final instar larvae	*solitaria* ...	91·09	90·72	91·13
	gregaria ...	88·42	88·09	88·62
L. exempta pupae	*solitaria* ...	73·96	73·04	73·31
	gregaria ...	73·83	72·84	73·49
S. abyssinia final instar larvae ...	*solitaria* ...	88·02	87·84	87·94
	gregaria ...	88·72	88·23	88·48
S. abyssinia pupae	*solitaria* ...	73·49	71·04	72·25
	gregaria ...	74·41	72·79	73·53
L. migratoria 5th-instar hoppers ...	*solitaria* ...	74·89	74·05	74·48
	gregaria ...	74·71	74·27	74·78
L. pardalina 5th-instar hoppers ...	*solitaria* ...	78·01	77·07	77·54
	gregaria ...	75·03	74·87	74·95

E. WATER CONTENT.

The two phases of all four species were analysed for their moisture content. The material included the final instar larvae and pupae of *solitaria* and *gregaria* of *L. exempta* and *S. abyssinia,* and the fifth-instar hoppers of *solitaria* and *gregaria* of *L. migratoria* and *L. pardalina*. In all the determinations, the insects were cut up into small pieces and dried in an oven at 110° C. until a constant weight was assured. The mean percentage of moisture for each species and phase is tabulated in Table XIII. Only the final instar larvae of *L. exempta* and the fifth-instar hoppers of *L. pardalina* showed a difference in moisture content as between *solitaria* and *gregaria* that was statistically significant. The *solitaria* larvae of *L. exempta* contained 91.13 per cent. moisture while *gregaria* contained 88.62 per cent., giving a difference of 2.51 per cent. A minimum difference of 2.25 per cent. would be significant at P=0.01.

The moisture content of the *solitaria* and *gregaria* hoppers of *L. pardalina* was 77.54 and 74.95 per cent. respectively, giving a difference of 2.59. Statistically a minimum difference of 2.59 per cent. would be significant at P=0.01. In these two species, then, the phase *solitaria* contained slightly more moisture than *gregaria.*

In the other two species no difference in moisture content was found between the two phases.

Of the four species analysed, the *solitaria* pupae of *S. abyssinia* contained the lowest percentage of moisture, *viz.* 72.25, while the *solitaria* larvae of *L. exempta* contained the highest percentage of moisture, *viz.* 91.13. The quantity of water in different insects ranges from less than 50 to more than 90 per cent. of the total body weight. In the adult of *Calandra granaria* it is only 46-47 per cent. while in the large Saturniid caterpillar, *Telea polyphemus,* it amounts to 90-92 per cent. (Buxton, 1932).

F. Summary and Conclusions: Biochemical Analyses.

In Table XIV a summary is given of the mean results obtained in the biochemical analyses of phases *solitaria* and *gregaria* of the four species dealt with. It will be seen that the lactic acid concentration of the whole body expressed in milligrams per gram of wet body weight varied from 0.1541 in the final instar *solitaria* larvae of *S. abyssinia* to 0.9461 in the *gregaria* pupae of *L. exempta.* Unfortunately no conclusions can be drawn as to the actual amount of lactic acid in the muscles, since the whole body, including all appendages, was analysed. Only those insects belonging to the same group are comparable, that is, the two species of Noctuids and the two species of Acridids. From Table XIV it is clear that both the *solitaria* and *gregaria* phases of *L. exempta* had a higher lactic acid concentration than *S. abyssinia.* No attempt was made to measure the degree of activity, but it was noticed that the larvae of *L. exempta* were more active than those of *S. abyssinia.* Since the production of lactic acid depends on the degree of activity, the conclusion seems warranted that *L. exempta* larvae were more active than those of *S. abyssinia.* A comparison of the lactic acid concentration of the two species of Acridids also seems to show that *L. pardalina* was more active than *L. migratoria.*

In the species and stages compared, a higher lactic acid concentration was found in phase *gregaria* than in phase *solitaria,* with *L. pardalina* as the only exception. Evidently then *gregaria* must have been more active than *solitaria.* In *L. pardalina,* where field hoppers were used, a higher lactic acid concentration was found in the solitary than in the *gregaria* phase which is difficult to explain.

The uric acid content of the blood of the four species varied from 14.36 milligrams per cent. in *gregaria* hoppers of *L. migratoria* to 51.11 in the *solitaria* larvae of *L. exempta.* The uric acid concentration of the *solitaria* individuals of *S. abyssinia, L. migratoria* and *L. pardalina* varied from 20.17 milligrams per cent. in *S. abyssinia* to 21.22 in *L. migratoria,* while in the *gregaria* individuals it varied from 13.36 in *L. migratoria* to 14.12 in *S. abyssinia,* thus the concentration in these three species did not vary appreciably. In the blood of the larvae of *L. exempta* on the other hand the concentration of uric acid was exceptionally high, in the solitary phase 51.11 milligrams per cent. and in the *gregaria* phase, 46.91 milligrams per cent. This high concentration of uric acid in the blood of

TABLE XIV.

A Summary of the mean Results obtained in the biochemical Analyses of Phases *solitaria* and *gregaria* of *L. exempta*, *S. abyssinia*, *L. migratoria* and *L. pardalina*.

Species and stage	Phase	Milligram lactic acid per gram wet body weight	Milligram per cent. uric acid	Percentage fat : dry weight basis	pH values of the blood	Percentage moisture
L. exempta final instar larvae	*solitaria* ...	0·3149	51·11	16·87	8·86	91·13
	gregaria ...	0·4633	46·91	23·57	8·55	88·62
L. exempta pupae	*solitaria* ...	0·7644	—	27·61	—	73·31
	gregaria ...	0·9461	—	36·06	—	73·49
S. abyssinia final instar larvae	*solitaria* ...	0·1541	20·17	28·36	—	87·94
	gregaria ...	0·2202	14·12	42·93	—	88·48
S. abyssinia pupae	*solitaria* ...	—	—	25·59	—	72·25
	gregaria ...	—	—	35·38	—	73·53
L. migratoria fifth-instar hoppers ...	*solitaria* ...	0·3036	21·22	11·11	6·814	74·48
	gregaria ...	0·3018	14·36	14·02	6·776	74·78
L. pardalina fifth-instar hoppers ...	*solitaria* ...	0·5602	20·31	12·79	—	77·54
	gregaria ...	0·5450	13·78	14·63	—	74·95

— No determinations made.

the larvae of *L. exempta* is difficult to explain. It will be seen that the uric acid values for the phase *solitaria* were consistently higher than for the *gregaria* phase.

The percentage of fat varied from 11.11 in the *solitaria* hoppers of *L. migratoria* to 42.93 in the *gregaria* larvae of *S. abyssinia*. In contrast with the uric acid values, the *gregaria* phase yielded consistently more fat than the *solitaria* phase.

The blood of *L. migratoria* had a slight acid reaction while that of *L. exempta* reacted on the alkaline side. In both species the blood of the *gregaria* phase had a greater acidity than that of the *solitaria* phase.

The percentage of moisture varied from 72.25 in the *solitaria* pupae of *S. abyssinia* to 91.13 in the solitary larvae of *L. exempta*. Differences worth mentioning were found only between the *solitaria* and *gregaria* phases of *L. exempta* and *L. pardalina*. In these cases the solitary phase yielded a higher percentage of moisture than the *gregaria* phase.

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References.

BABERS, F. H. (1938). An analysis of the blood of the sixth-instar Southern Army Worm (*Prodenia eridania*).—J. agric. Res., **57**, pp. 697-706.

BROWN, A. W. A. (1937). The excreta of a grass-hopper (*Melanoplus bivittatus* Say).—J. exp. Biol., **14**, pp. 87-94.

BUTLER, C. G. & INNES, J. M. (1936). A comparison of the rate of metabolic activity in the solitary and migratory phases of *Locusta migratorioides* R. & F. —Proc. roy. Soc., (B) **119**, pp. 296-304.

BUXTON, P. A. (1932). Terrestrial insects and the humidity of the environment. —Biol. Rev., **7**, pp. 275-320.

*FARKAS, K. (1903). Ueber den Energieumsatz des Seidenspinners während der Entwicklung im Ei und während der Metamorphose.—Arch. ges. Physiol., **98**, pp. 490-546.

FAURE, JACOBUS C. (1923). The life history of the brown locust.—J. Dep. Agric. S. Afr., **7**, pp. 205-224, 2 pls.

FAURE, JACOBUS C. (1932). The phases of locusts in South Africa.—Bull. ent. Res., **23**, pp. 293-405, pls. xiv-xxxviii, 1 map.

FAURE, JACOBUS C. (1943a). The phases of the lesser army worm (*Laphygma exigua* (Hübn.)).—Fmg in S. Afr., **18**, pp. 69-78, 1 fig.

FAURE, JACOBUS C. (1943b). Phase variation in the army worm, *Laphygma exempta* (Walk.).—Sci. Bull. Dep. Agric. For. S. Afr., no. 234, 17 pp., 1 col. pl.

FISHER, R. A. (1936). Statistical methods for research workers.—Edinburgh, Oliver & Boyd, xii + 339 pp.

FOLIN, O. (1933). Standardized methods for the determination of uric acid in unlaked blood and in urine.—J. biol. Chem., **101**, pp. 111-125.

FOLIN, O. (1934). The preparation of sodium tungstate free from molybdate, together with a simplified process for preparation of a correct uric acid reagent (and some comments).—J. biol. Chem., **106**, pp. 311-314.

FRIEDEMANN, J. H. & CRAESER, J. B. (1933). The determination of lactic acid.—J. biol. Chem., **100**, pp. 291-308, 1 fig.

HATTINGH, C. C. (1941). The biology and ecology of the army worm (*Laphygma exempta*) and its control in South Africa.—Sci. Bull. Dep. Agric. For. S. Afr. no. 217, 50 pp., 7 pls., 2 figs.

JOHNSTON, H. B. & MAXWELL-DARLING, R. C. (1931). On the occurrence in the Sudan of *Locusta migratorioides* Rch. & Frm., and its associated phases.—Bull. ent. Res., **22**, pp. 399-416.

*SCHÜTZE, W. (1932). Untersuchungen über die chemische Zusammensetzung der Arthropodenmuskulatur.—Zool. Jb., (3) **51**, pp. 505-546, 1 fig.

SMIT, C. J. B. (1939). Field observations on the brown locust in an outbreak centre.—Sci. Bull. Dep. Agric. For. S. Afr. no. 190, 143 pp., 34 figs.

*STRAUSS, J. (1911). Die chemische Zusammensetzung der Arbeitsbienen und Drohnen während ihrer verschiedenen Entwicklungsstadien.—Z. Biol., **56**, pp. 347-397.

*STRELNIKOV, I. D. (1936). Effect of solar radiation and micro-climate upon the body temperature and behaviour of the larvae of *Locusta migratoria* L.—Trav. Inst. zool. Acad. Sci. U.R.S.S., **2**, pp. 637-733, 16 figs., 22 tables.

*TANGL, F. (1909). Zur Kenntnis des Stoff und Energieumsatzes holometaboler Insekten während der Metamorphose. (6. Beitrag zur Energetik der Ontogenese.)—Arch. ges. Physiol., **130**, pp. 1-54.

THEODOR, O. (1936). On the relation of *Phlebotomus papatasii* to the temperature and humidity of the environment.—Bull. ent. Res., **27**, pp. 653-671.

UVAROV, B. P. (1921). A revision of the genus *Locusta* L. (= *Pachytylus* Fieb.), with a new theory as to the periodicity and migrations of locusts.—Bull. ent. Res., **12**, pp. 135-163, 8 figs.

*WEINLAND, E. (1909). Chemische Beobachtungen an der Fliege *Calliphora*.—Biol. Zbl., **29**, pp. 564-577.

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* Papers marked with an asterisk were not consulted in the original.

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FACTORS INFLUENCING THE INTERACTION OF INSECTICIDAL MISTS AND FLYING INSECTS.

PART I.—THE DESIGN OF A SPRAY TESTING CHAMBER AND SOME OF ITS PROPERTIES.

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Introduction.

The investigations described in this paper, and in others of the series which it is hoped to publish in the near future, had their origin in the sudden increase in the demand for liquid insecticides which developed when large scale military operations spread to the Mediterranean and Far Eastern regions. Hitherto pyrethrum flowers had provided the main toxic ingredient for mosquito and fly control sprays, but the world demand could no longer be met from Kenya, the only remaining source of supply. The first object of the work to be described was, therefore, to develop as soon as possible spray formulae suitable for use against mosquitos, which would make less demands on the limited supply of pyrethrum extract. For this purpose a spray testing chamber specially adapted for use with mosquitos was designed. In this chamber substances known or claimed to be effective substitutes for pyrethrins where the house-fly (*Musca domestica*, L.) was concerned were tested on mosquitos also. The insect mainly employed in this work was the yellow fever mosquito, *Aëdes aegypti*, L., which can be bred easily in captivity. At a later stage a certain number of comparative experiments were carried out on *Anopheles maculipennis*, Meigen. The results obtained will form the subject of a later paper in this series.

In order to supply the urgently required information concerning alternative mosquito control sprays, the work on the development of new formulae was carried out under a set of rather arbitrarily chosen conditions and with no real knowledge of the characteristics of the newly designed spray chamber. Subsequently, however, it has been possible to rectify this omission and the present paper, besides describing the spray testing equipment, also discusses the repeatability of the method and the effects of departing from the various arbitrarily chosen testing conditions.

Considerations affecting the Design of a Spray Testing Chamber.

Before describing in detail the construction and mode of operating the spray chamber used in the course of this work, it is necessary to discuss the various factors that have to be borne in mind when designing equipment of this kind. The main requirements which the apparatus must fulfil are: that it should give repeatable results, and that the order of efficiency of insecticides as measured by the laboratory procedure should be the same as those found under practical conditions. That is to say that ideally the apparatus should embody the essential features of practical conditions, since the effect of any deviation from them is unknown, and at the same time give repeatable results. But a consideration of the relationships between the spray droplets and the insects, which in fact occur in practice, leads to the conclusion that they are often such as would introduce variability into the results. For example, when a room is sprayed the insects present may fly through the cone of spray droplets issuing from the atomising nozzle. In this cone the droplets are at their largest, since there has been little time for evaporation, and also they are moving rapidly. At this time, therefore, they possess their maximum momentum and would, through their own movements, impact with moving or stationary insects. Furthermore there may be present in the cone a percentage of large droplets which would be lost by sedimentation unless the insects accumulate them by passing through the mist cone. Outside the cone of mist droplets leaving the gun there will only be slowly moving, smaller, partially evaporated droplets. Contact between these droplets and the insect will be brought about by the flight movements of the insects though the mist and the dose accumulated by the individual insect will be largely an expression of the distance, and perhaps the velocity, at which it has flown. It can be seen, therefore, that when the main movement resulting in a collision between a spray droplet and an insect is that of the spray droplet, contact will be more or less at random on any part of the body, whereas when the insect's flight movements are responsible for the impaction it will take place on certain definite sites determined by the nature of the air currents set up around its body. Whether the collisions which take place between the insecticide droplets and insects which occur in practice are brought about mainly by the movements of the insects or of the droplets will depend very much on conditions and chance circumstances such as the possibility of getting the insects within the mist cone and their behaviour. In the case of mosquitos, which often rest in sheltered places, it is possible that they will not detect the first irritation of the spray and emerge until the application is over so that their own flight movements only will be responsible for impaction. Any method reproducing this degree of variability of conditions is unlikely to give repeatable results.

Very little is known concerning the interaction between flying insects and an atomised spray mist under the ordinary testing conditions and it has been the practice to standardise every possible variable in the system in order to obtain repeatable results, without in many instances any clear understanding of what was taking place. Very serviceable results have been obtained in this way by the Peet-Grady method (Peet & Grady, 1928 and revised). The adoption of such a procedure involves standardising the temperature and humidity of the air, the light conditions in the cabinet, the type of atomising gun, the spraying pressure and the volume and shape of the spray chamber. In addition it is necessary to have supplies of the test insect reared under controlled conditions. In this way when the test is carried out, environmental factors, the atomisation of the spray, and the resistance of the insects are all largely controlled. It has been shown, however (Murray, 1940), that in the Peet-Grady chamber, even under these conditions, the dose of insecticide reaching individual flies varies greatly. It seems probable that this variation is brought about by the movement of the flies in relation to the point or points of injection of the insecticide and also by the fact that certain flies are struck by relatively large droplets while others escape. Such contingencies seem to be inseparable from any testing procedure in which the insects are introduced into the cabinet before the spray and are allowed free movement so that they may or may not come within the cone of mist issuing from the atomiser.

In order to avoid these disadvantages associated with the Peet-Grady procedure two steps were taken: the distribution of the insects in the chamber was controlled by confining them in cages and the exposure was not made until a definite interval after spraying. Both procedures had the effect of preventing the insects from making contact with the coarser spray droplets and associated with the former provision there was the additional advantage that it was much easier to collect the mosquitos that were not paralysed by the spray in the small exposure cages. There are two further important consequences of the procedure here adopted. In the first place, the insects only accumulate spray droplets as a result of their own flight movements, and secondly, it has been shown (as will be explained later) that both the practice of using caged insects and of waiting for a certain time after spraying before introducing the insect exposure cages into the spray chamber, are attended by the same disadvantage: they prolong the interval between the time when the spray droplets leave the atomiser and the moment when they reach the insect. During this period the spray droplets will have an opportunity to evaporate and if two sprays with dissimilar volatility characteristics are being compared differences in the droplet size distribution of the two mists will become established. The more volatile spray will, of course, give rise to smaller droplets which, below a certain limiting size, do not impact so readily upon the insects. This evaporation effect is particularly apparent at volume dosages in the region below about 15 c.c. of spray fluid per 1,000 cubic feet. Above this level the evaporation rate of kerosene base sprays is depressed, due to the partial saturation of the atmosphere with the vapour of the evaporating kerosene. It is therefore necessary, when comparing the toxicity of materials by this technique, to be certain that the same solvent is used in the various formulae and that they contain approximately the same quantity of non-volatile ingredients. This limitation of the technique was not foreseen and has the effect of rendering it less generally useful, but the method has much to recommend it when accurate comparisons between formulae of known composition are required, or when general investigations into the interaction of flying insects with insecticidal mists are being carried out.

Where a spray chamber is constructed in the first place for the routine testing of insecticides, ease and rapidity of operation are very important considerations which have led to the development of the Turntable method (Campbell & Sullivan, 1938) and more recently to other small scale methods (Kearns & March, 1943; Allen, Dicke & Brooks, 1943). In this connection such factors as the size of the chamber to be cleaned between tests and subsequently air conditioned and the work involved in collecting the insects after a test exposure are important. It will be readily appreciated that ease of operation suggests the smallest possible chamber since this can be rapidly cleaned and air conditioned but on the other hand it has to be recognised that the conditions in very small chambers are more or less artificial. In such cases it becomes difficult to apply the small dose of insecticide which is required especially for susceptible insects, such as mosquitos, while the behaviour of the insects is also modified. The other important point concerned with ease of operation is the comfort of the operator. Usually the tests have to be conducted at an uncomfortably high temperature and humidity. The present procedure avoids the necessity of air conditioning the whole working room as the following description of the apparatus makes clear.

Design of the Spray Chamber and surrounding Cabinet.

In principle the spray chamber designed consists of an enclosure which can be brought to any temperature and humidity above those naturally prevailing. By the use of refrigerating plant and air dryers it would not be difficult to extend the range of working conditions. The room in which the cabinet is housed remains at the ordinary living room temperature and humidity which is a considerable advantage to the operator.

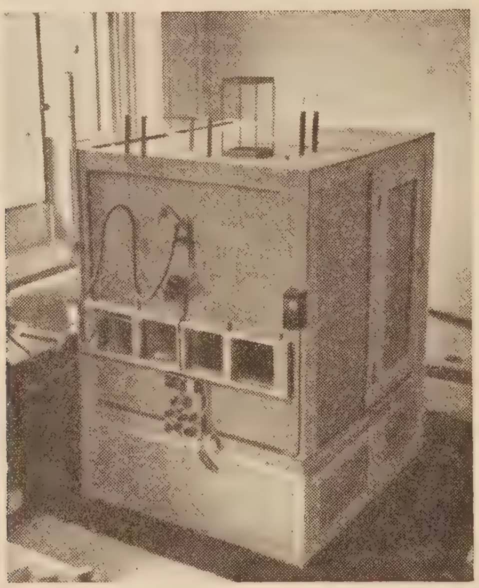

FIG. 1.—The Spray Cabinet. A general view showing the door on the right hand side and below the hinged panel giving access to the temperature control equipment. On the front can be seen the spray gun, the electric motor for the internal fan, the four ports for introducing the mosquito-exposure cages and the switchboard. To the left of the front is the manometer and the two knobs controlling the ventilation ports are also just visible. On the top of the cabinet are the wet and dry bulb thermometers and the thermometer in the air space between the outer cabinet and the inner metal chamber. Resting on the top there are also two mosquito-exposure cages (framework only).

The spray chamber was made of zinc plate about 25 thousandths of an inch thick and measured 42 ins. wide by 48 ins. deep by 48 ins. high. Actually the one constructed had a volume of 54·5 cu. ft. (1543 lit.). It was supported underneath by several wooden cross pieces in the upper part of a constant temperature cabinet made of "Masonite" in a wooden framework. The arrangement is shown in fig. 1. This outer cabinet measured 50 ins. wide by 56 ins. deep by 72 ins. high. There was thus an annular space four inches wide surrounding the chamber on the top and all four sides with a space 18 ins. deep beneath containing the temperature control equipment. One of the sides of this lower compartment was made to open disclosing a baffle board parallel to the front of the cabinet in which a fan was mounted. The half of the cabinet behind this board contained the capsule, which together with the "Sunvic" hot wire vacuum switch, controlled the temperature. In the space in front of this board were placed two 750-watt electric bowl-fire elements mounted on a "Uralite" base. When the fan in the baffle board was running the air circulated towards the front of the cabinet and up through the space between the chamber and surrounding cabinet, over the top, and finally down the back. In this way the inner metal chamber could be heated fairly uniformly on all sides. Two other points should be mentioned in connection with the air circulating system. The first is that the air circulation does not pass through the cavity in the door and the other that in the side opposite the door a vertical baffle was arranged between the chamber and the cabinet and joined to the baffle carrying the air circulating fan. This prevented the air short circuiting back to the rear of the chamber and forced it to pass round the top. On the door side the framework of the door served the same purpose. Before passing on to a description of the inner metal chamber it is convenient to describe the construction of the door already mentioned. The door measured 23 ins. wide and 45 ins. high, the inner face was metal and the outer face "Masonite". These two faces were separated by the usual four inch wide cavity so that when the door was closed the two faces fell into line with the rest of the chamber and cabinet. In order that it might fit closely, the door was made slightly smaller on the inside than the outside and a similar slope was arranged in the door frame. The inner metal chamber was constructed in two halves which were bolted together during assembly. As has already been stated there was a door on one side, while on the side opposite there were two ventilation points, an intake and output, both 6 ins. square, so that the waste spray vapours could be passed to the exterior. These two ports were fitted with sliding doors on the outside of the metal chamber which were connected with rods and could be operated from the front of the cabinet. The intake port was placed near the front lower corner of the side 6 ins. from the bottom of the chamber and the same distance from the front. The output is similarly placed in the back upper corner. It may be mentioned here that the intake port was just carried through to the outside of the "Masonite" cabinet by a few inches of duct while the output was connected to the outside of the building, an extraction fan being mounted near the window end of the duct.

The back of the chamber was perforated by four round openings 4 ins. in diameter which, in the finished apparatus, were covered by a sheet of glass mounted in a frame screwed on to the outside of the chamber. The centres of these round windows were 10 ins. apart and on a line 16 ins. from the floor of the chamber. Opposite these windows there were similar openings 5 ins. in diameter covered with glass in the outer cabinet and on the outside a row of four 60-watt electric light bulbs were mounted in an open-topped light box.

In the front of the chamber opposite the windows just described there were four observation ports measuring 8 ins. square with 2 ins. in between. These ports passed from the inner metal chamber through the intervening air space to the outer cabinet in the form of short metal ducts ending flush with the outer walls. Each port was closed by separate sliding glass doors which worked in a framework mounted on the outside of the cabinet. These sliding doors were lifted to permit the introduction of the insect cages, as described later, and also served as windows through which the test insects could be observed. The four ports were 12 ins. from the floor of the chamber while in the centre of the front 28 ins. from the floor was a fan, and at 39 ins. the spray gun aperture. The fan motor was mounted on a bracket outside the cabinet and connected across the air space by a long spindle which revolved in a bush screwed on to the zinc walls of the chamber. The spray gun employed was an Aerograph M.P. gun with a standard 3 in. extention fitted with a No. 1 conical nozzle. The gun extension passed through a piece of galvanised piping which was screwed to the inner cabinet and rested in a hole in the outer "Masonite" cabinet. When the gun extension was passed into the piping the nozzle reached just inside the inner chamber and the handle of the gun rested in a U-shaped block which prevented any lateral movement.

The top of the chamber was fitted with wet and dry bulb thermometers which could be raised and lowered so as to avoid contaminating the thermometers, especially the wet bulb, with spray mist. These two thermometers were mounted in brass tubing which slid through slightly wider pieces of similar tubing permanently mounted on the inner metal chamber and crossing the air space between the two cabinets. The sides of the lower ends of the inner brass tubing were partly cut away so as to permit free circulation of air around the thermometers. The bottom ends of these inner tubes were covered with flat plates of a slightly greater diameter than the tubes which closed against the roof when the thermometers were drawn up. Within the lower part of the wet bulb tube there was a small glass specimen tube which provided the water supply for the wick. Details of these arrangements can be seen in fig. 2. Besides these two thermometers there was a third with its bulb in the air space between the two cabinets.

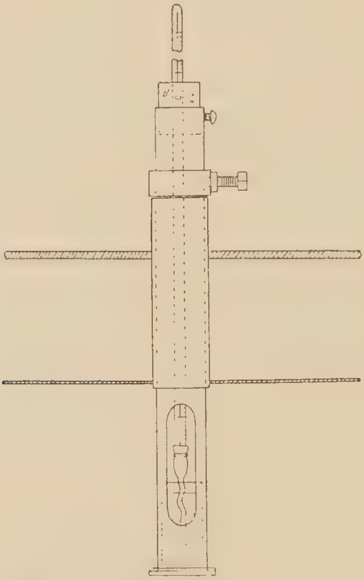

FIG. 2.—The wet bulb thermometer showing the inner metal tube with part of the side walls cut away and the wider piece of tubing (fixed between the inner chamber and outer cabinet) through which it slides.

In the floor of the chamber there were also four glass-covered windows 4 ins. square in a row 3 ins. from the front, one of which was in line with each of the four windows in the front of the cabinet already mentioned. There was a space of 4 ins. between one window and the next. These windows also had 40-watt electric light bulbs mounted under them and together with the lamps at the back of the cabinet served to light up the insect exposure cages. The insect exposure cages, which will be described later, were passed into the cabinet through the four windows in the front and rested on a horizontal metal shelf level with the bottom of the windows. This shelf was removable and stretched right across the cabinet from side to side but was only 18 ins. deep from back to front. It was perforated with four rows of three holes measuring 3 × 6 ins. which came in line with the windows. When the insect exposure cages were placed in position on this shelf the lights from the windows on the bottom shone up through three holes in the shelf and so illuminated the cages from underneath. The lamps at the back of the cabinet directed light through the exposure cages from the ends. On the front of the cabinet there was a switchboard which forms the last feature to be described; it carried five switches and a resistance: one each for the two banks of lights already mentioned, one and the resistance for the fan operating within the metal spray chamber, and one each for the fan and heaters of the temperature control equipment.

Description of the accessory Equipment.

Various items of equipment which were used in conjunction with the spray chamber must be described separately.

(*a*) *The Atomising Equipment.*

The spraying equipment consisted of an Aerograph M.P. atomising gun fitted, as already described, with a standard three-inch extension and a No. 1 nozzle and set to give a fine degree of atomisation. The compressed air was supplied from cylinders via a double stage reducing valve (British Oxygen Co.) and a sintered glass air line filter. The spraying pressure was finally measured on a mercury manometer. The atomising gun was modified in two ways: the trigger which normally operates the gun was held open permanently by a metal band around the handle so that the performance of the gun should not vary owing to continually opening and closing the liquid flow valve. This modification in turn necessitated substituting the gravity feed by a suction feed and fitting a tap on the air line so that the gun could be turned on and off. These modifications are shown in fig. 3.

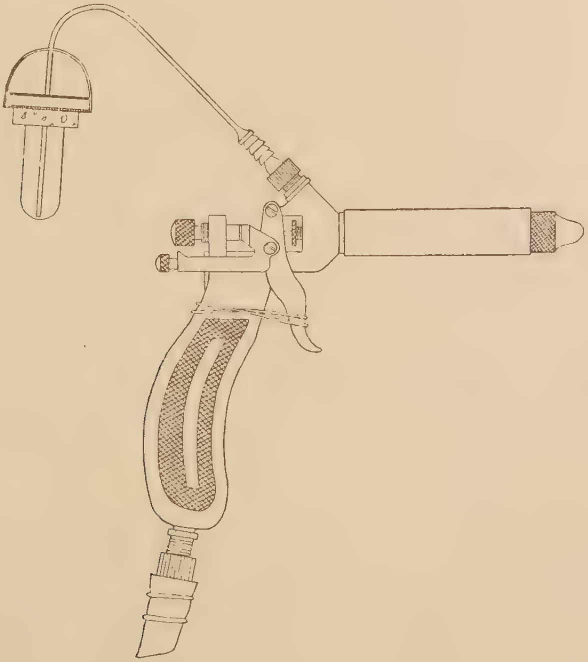

FIG. 3.—The Aerograph M.P. atomising gun modified as described in the text.

(*b*) *The Insect Exposure Cages.*

Various types of cages in which the insects could be exposed to the spray mist were made up all on the same principle with wire and zinc strip framework and metal or gauze walls, but one type was finally chosen for all the ordinary tests. This consisted of a framework of zinc strip ends 1 in. wide with copper gauze (14 mesh to inch 35 gauge wire) soldered to the inner ends. Each cage was 7 ins. square at the end and 14 ins. long, but since the gauze was attached to the inner margin of the zinc strip ends (1 in. wide) the internal length of the cage was only 12 ins. The two ends so constructed were joined together by No. 10 gauge galvanised wire at the four corners. This wire was soldered along the corners of the metal strip ends on the insides, *see* fig. 4. The sides of the cage were made up freshly on each occasion from a roll of white paper (a standard 42 in. wide roll cut by supplier into three) which was clipped on to the cage ends with simple clips made by folding over pieces of sheet zinc so as to form a double strip measuring 1 × 6¾ ins. which just fitted over the paper and metal cage ends. When the paper had been fitted into position it was cut from the roll and the slightly overlapping ends were fastened together along one side with gummed paper tape. A triangular slot was next cut in one of the side walls leaving the triangle uncut at the base. Strips of gummed paper tape were applied to the edges of the flaps to complete the cage, which was then ready to be filled with insects.

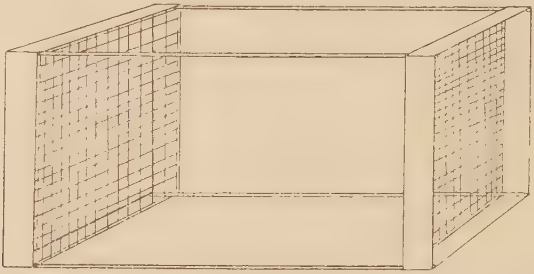

Fig. 4.—The framework of an insect exposure cage as described in the text.

(*c*) *The Humidifying Equipment.*

The cabinet was very simply brought to the desired humidity (as shown by the wet and dry bulb thermometers in the roof) by blowing in steam from a flask of boiling water. A Buchner filter flask was fitted to the end of the steam line to act as a condensation trap. The steam entered via the neck of the flask and issued from the side arm.

When steam was being used it was found to be convenient to keep a small pilot flame constantly burning under the flask, so that the water was kept just below the boiling point. When the steam was required another Bunsen was turned on and ignited from the pilot.

(*d*) *The Box for carrying the Insect Exposure Cages.*

Since the insects have to be transferred from the breeding room to the cabinet a Plywood Carrying Box measuring 15 ins. × 15 ins. × 7½ ins. deep was made. This was stored in the insect breeding room and brought to the spray cabinet, just before the time at which the insects were to be inserted. In this way the insects were exposed only momentarily to a lower temperature before spraying. At the end of the test the box was again used for returning the insects to the constant temperature and humidity room for recovery.

(*e*) *The Recovery Cages.*

After exposure to the spray mist the insects were transferred to clean recovery cages which consisted of a cylinder of wire gauze approximately 3·5 ins. in diameter and 4·0 ins. high which fitted into a petri dish at each end. The ends of the cylinder were bound with bias binding to make a tight fit. A hole one-half inch in diameter was cut in the side of the cage and edged with solder. This hole served two purposes: to introduce insects which had not been knocked down during the test by means of a special catcher (described below) and later, when the transfer had been completed, it was plugged with a piece of wet cotton wool which provided the recovering insects with a little moisture during the following 18-24 hours. A lump of sugar was also supplied for the insects in a small hammock stretched across the top of the cage. When the cage was being used the lower petri dish was covered with filter paper.

Method of Rearing Aëdes aegypti for Insecticidal Tests.

The test insect employed was *Aëdes aegypti*, chosen because it breeds readily in captivity. The method employed for rearing large numbers of insects for testing purposes has already been described (David, Bracey & Harvey, 1944). In outline the method consisted of maintaining the culture in a breeding room held at 28° C. and 70 per cent. R.H. The larvae were fed on a four-day old infusion of dried bread crumbs and water and the adult ovipositing females were given a human blood meal at two days old and immediately after each subsequent batch of eggs had been laid. The main stock of insects which were normally used in the spray tests at 1-4 days old were fed on sugar, raisins and water. All the adults were maintained in mosquito netting cages 1 ft. square with a removable top in which was a sliding door covering an opening in the form of a triangle with 3 in. sides. This opening was employed in transferring the insects to the exposure cages as will be described later. About two to three thousand insects were allowed to emerge into each of these stock cages.

Handling the Insects before and after Spraying.

Special methods were devised for transferring the insects from the stock and exposure cages which involved the minimum amount of handling. The transference to the insect exposure cages was made through the triangular openings in these two cages which have already been described. The two openings were simply opposed and by moving the cages up and down through the air a few times a sufficient number of insects (approximately 100) were quickly transferred. The paper triangle was then gummed into position in order to seal the exposure cage. Insects which were exposed in the spray chamber were not always knocked down; if they were, the transference to the cylindrical recovery cages was made by tipping out the insects through a hole which was torn in one corner of the paper exposure cage. When the insects were not knocked down, however, each individual had to be caught. This was effected by attaching a plywood board with a circular opening 4 ins. in diameter fitted with a short mosquito netting sleeve to the exposure cage. It was found that spring stationery grips were very convenient for this purpose. One hand was inserted through the sleeve and a hole was torn in the paper covering of the cage. A catching tube was then operated through the sleeve until all the insects were removed. Many insects may be conveniently collected at a time and then blown gently into the recovery cage through the hole in the side already mentioned. The catching tube employed was a modification of that described by Lewis (1933). It consisted of a piece of glass tubing, internal bore 0·4 ins. and 9 ins. long bent near the middle at an angle of about 120 degrees. Into one end of this was inserted a short piece of tightly fitting narrower tubing the end of which was covered with boulting silk. The rubber suction tube was fitted to this and if necessary could be pushed over the wide tube also. Insects could be very quickly collected into a tube of this kind and appeared to suffer no injury in the process.

The Standard Testing Conditions.

In order that the cabinet which has just been described could be used for the urgent programme of anti-mosquito spray formulation already mentioned, it was necessary to decide upon a set of testing conditions in a rather arbitrary manner. The considerations which led to the selection of the set of conditions which were utilised under normal circumstances may now be considered and later the effects of departing from them will be illustrated.

(*a*) *Temperature and Humidity.*

The experience of earlier workers had shown that a temperature of 28°C. and a relative humidity of 70 per cent. were favourable for breeding *Aëdes aegypti* (Lewis 1933, Leeson 1939). In order to avoid any uncontrolled effects associated with a transference from one environment to another, the same temperature and humidity were selected for the spray cabinet.

(*b*) *The Exposure of the Insects.*

For the reasons already given, it was decided not to expose the insects to the spray mist until all the coarser droplets had deposited. Deposition of the spray was followed by exposing squares of white paper on the floor of the cabinet after injecting a dyed spray. It became apparent that with volume doses up to 3 c.c. injected the main deposition was completed well within four minutes, and this interval was adopted in the standard procedure.

(*c*) *The Volume of Spray Injected.*

The volume of spray injected into the chamber cannot be regarded as an independent variable determining only the quantity of toxic material present since, as will be shown later, variations in volume of spray bring about changes in the rate of droplet evaporation and so influence the particle size and persistence of the mist. In the present instance the volume of spray fluid to be injected into the chamber was determined by the demands of the programme of insecticide development which required that the insecticides should be compared in efficiency with a standard solution, the Official Test Insecticide. This contained 0.1 per cent. wt./vol. of Pyrethrins I and II (supplied and standardised by the National Association of Insecticide and Disinfectant Manufacturers Inc., New York). In order to obtain the most sensitive comparisons the dose of the standard insecticide should produce a kill of around 50 per cent. 24 hours after treatment. It was found that a volume of 0·7 c.c. actually injected into the chamber (1·0 c.c. in the spray gun reservoir) produced this result and was, at the same time, in line with the dosage commonly recommended in practice, being equivalent to 12·8 c.c. /1,000 cu. ft. compared with 10 c.c. per 1,000 cu. ft. usually applied for mosquito control.

The Testing Procedure.

About half an hour before a test was to be carried out the heaters and air circulating fan of the cabinet were switched on and the water boiler also. The chamber was then allowed to warm up with all the doors and ports closed, with the internal fan running and the wet and dry bulb thermometers lowered. When the desired temperature had been reached, or a little before, the humidifying process was started by placing the Buchner filter flask (which, as will be remembered, acted as a water trap at the end of the steam line) on the ledge of one of the four front windows. Just before the wet bulb thermometer showed the predetermined reading required for 70 per cent. relative humidity the steam was cut off and conditions within the chamber were allowed to stabilise for a few minutes. When the temperatures were properly adjusted the thermometers were drawn up, the internal fan was stopped and the spray fluid (0·7 c.c.) was injected into the chamber by means of the M.P. atomising gun operating at 12·5 lbs. per sq. in. A standard procedure was followed when spraying: the air was turned on and allowed to pass for 25 seconds. In this way the volume of spray which remained in the gun was always the same and the exact amount injected could therefore be determined. The rather large volume of air passed through the gun also assisted in stirring up the atmosphere in the chamber. Four minutes after the time at which spraying was commenced two or more insect exposure cages each containing about 100 insects were introduced into the chamber from the carrying box, and placed on the shelf. The glass doors through which they had been introduced were lowered as quickly as possible, and the number of insects paralysed ("knocked down") was recorded after two, four, six, eight and ten minutes. During the exposure the interior of the chamber was illuminated by the lamps at the back and under the floor. At the end of the ten-minute exposure period the extractor fan was switched on and the exhaust ports were opened. The exposure cages were placed quickly in the carrying box again and returned to a separate constant temperature room maintained at 28°C. and 70 per cent. R.H. where the insects were transferred to the recovery cages. After each test the spray gun was washed out with petroleum ether and the walls of the chamber were wiped down with a duster damped with the same solvent. The chamber was then allowed to air with the extractor fan running for about ten minutes before preparing for the next test.

Assessment of the Results.

Each batch of insects employed for testing purposes contained individuals between one and four days old. An exact number of insects of known sex ratio could not be easily introduced into the spray exposure cages. The test batches therefore varied in number between one and two hundred (usually nearer the former) and the sex ratio was determined for each batch when the kill was assessed 24 hours later. Although this procedure was not an ideal one it had the advantage of reducing the labour involved in handling the insects to a minimum. The chief objection was that it led to inaccuracies in making comparative determinations of the rate of knockdown since the percentage of the more susceptible males varied in the different test batches.

After 24 hours had elapsed the separate percentage kills of males and females were determined and the average of the figures for the two sexes was reported as the final percentage kill. Any insect capable of the slightest movement at the time at which the results were assessed was counted as alive. In certain of the tables the results of the individual tests are reported as percentage kills together with the average percentage kill. In all cases the results of the individual tests were converted to angles (Bliss, 1938) on which an analysis of variance was carried out and the average angles and their standard errors are also reported.

Examples of the Application of the Method.

When using the equipment described above for making comparisons between insecticides having different effects on the insect and different volatility characteristics, it soon became apparent that special provisions would have to be made so that these essential differences could be taken into account. In order to understand the reasons why these precautions have to be taken it is necessary to anticipate the results of experiments which will form the subject matter of a later paper in this series. Briefly it may be stated that the quantity of insecticide accumulated by the insects from the sprayed atmosphere depended on (*a*) the total distance which the insects flew whilst exposed, since by far the major portion of the dose was accumulated by impaction during flight and (*b*) the particle size of the insecticidal mist, since very small droplets did not impact as readily as those about 5-10 microns in diameter. The object of the precautions was therefore to ensure that the insects always accumulated approximately equal doses of insecticide when they were exposed in the spray chamber. In order that this might be the case the flight activity of the groups of insects being exposed must be reasonably similar and so must the particle size distributions of the spray mists.

In the examples which follow the application of the method to sprays of different properties is discussed in greater detail, and these examples are intended both to demonstrate the efficiency of the method and the precautions which have to be taken when it is applied.

(*a*) *Sprays containing Pyrethrins as the Toxic Material.*

When a cage containing a batch of *Aëdes aegypti* was introduced into a sprayed atmosphere the insects were irritated by the pyrethrins and they began to fly around almost incessantly until they were all knocked down. This occurred in about 8-10 minutes with a dose sufficient to produce a kill in the 50 per cent. region 24 hours later. Even with doses of one-fifth or one-tenth of this amount, which produced very little knockdown and no kill, the insects were still stimulated into active flight. The uniformly active behaviour of the insects when exposed to pyrethrins made the comparison of the insecticidal efficiency of such sprays a simple and sensitive procedure. As an example a standard solution of 0·1 per cent. wt./vol. pyrethrins in odourless kerosene (the Official Test Insecticide—O.T.I.) was diluted to various strengths with essentially the same solvent, and the solutions were sprayed following the procedure described. The results obtained are shown in Table I. It can be seen clearly that the rate of paralysis ("knock-down") is a much less sensitive method of estimating the relative insecticidal efficiency of the solutions than the final percentage killed.

Table I.

An example of the standardised procedure applied to the comparison of pyrethrum sprays of various concentrations.

Insecticide sprayed	Average % paralysed after (mins.) 2	4	6	8	10	24-hr. % kill				Average % kill in 24-hrs.	Average angle ± 1·5°
Pyrethrins 0·10% w/v	10	90	100	100	100	59,	56,	65,	54	59	50
,, 0·08% ,,	10	90	100	100	100	49,	45,	45,	36	44	41
,, 0·06% ,,	10	80	100	100	100	17,	19,	22,	24	21	27
,, 0·05% ,,	5	75	95	100	100	11,	10,	16,	9	11	20

(*b*) *Sprays containing DDT* (2, 2-*bis* (*p-chlorphenyl*)-1, 1, 1-*trichlorethane*) *as the Toxic Material.*

As has already been explained, it was found that mosquitos (*Aëdes aegypti*) were invariably stimulated into active flight by exposure to sprays containing pyrethrins. Sprays consisting of about 0·5 per cent. wt./vol. of DDT in odourless kerosene on the other hand did not produce this effect. In this connection it should be noted that, for as yet unexplained reasons, insects drawn from some stock cultures flew naturally much more actively than those from other cultures.

In the presence of pyrethrins the naturally inactive insects became active and the resultant kills recorded in the two cases were not usually very different. With DDT sprays, on the other hand, the two groups would retain their natural state of activity or inactivity so that a considerable difference in kill would result which was merely an expression of the lower dose accumulated by the inactive insects.

As a result of the above observations, it was realised that legitimate comparisons between the efficiency of pyrethrum and DDT sprays could only be made on active insects. If inactive and active insects were used indiscriminately the apparent order of efficiency of a DDT and a pyrethrum spray might be reversed as the results recorded in Table II show. Thus when compared on cultures 1 and 2 the DDT solution gave a lower kill than the pyrethrin solution, on culture 4 the kills were approximately equal while on culture 3 the DDT solution appeared to be considerably superior.

TABLE II.

Pyrethrum and DDT sprays compared by the standardised procedure using batches of insects that showed different natural levels of flight activity.

Insecticide	Inactive insects			Active insects		
	Culture number	Average 24-hr. % kill	Average angle	Culture number	Average 24-hr. % kill	Average angle
Pyrethrins 0·1% w/v...	1	38	38±1·9°	3	50	45±3·1°
	2	33	35±2·0°	4	51	46±1·5°
DDT 0·5% w/v...	1	13	21±1·9°	3	78	63±3·1°
	2	7	15±2·0°	4	54	47±1·5°

Insects in cultures 1 and 2 were less active than those of 3 or 4. Each average is based on four determinations.

In the course of later experiments with DDT solutions, it became apparent that in general the results were much less consistent than had been obtained with pyrethrum sprays. These variations disappeared when 0·01 to 0·02 per cent. wt./vol. of pyrethrins were added to the DDT sprays, since the insects were then excited into much more active and uniform flight. At the concentrations stated the pyrethrins present caused no kill and little or no knockdown. This observation suggests the practical conclusion that it would be advantageous to add a percentage of pyrethrins to anti-mosquito sprays so that the insects would be stimulated to leave the sheltered resting places which they commonly frequent and so become exposed to a heavier dose of spray.

(c) *Sprays that have appreciably different Volatilities.*

When a kerosene base insecticidal spray is applied at the volume dosage level adopted in the spray chamber (12·8 c.c./ 1,000 cu. ft.), or commonly in practical sprayings for mosquito control (10 c.c./1,000 cu. ft.), the spray droplets quickly evaporate leaving residual particles of a size which is largely determined by the content of non-volatile material in the spray. It will be shown later that a given spray dispersal becomes decreasingly effective with time. With mists having an initial maximum particle size of about 20 microns this decline in insecticidal efficiency is due more to the rapid decrease in particle size associated with the evaporation of the carrier rather than to the slower fall of concentration of actual insecticide in the air space due to deposition.

At higher volume dosage levels than those considered above, the influence of the volatility characteristics of the spray on droplet size, and so on insecticidal efficiency, is less apparent. This is due to the marked depression of the rate of evaporation of the kerosene solvent, once the atmosphere surrounding the spray droplets has become partially saturated with kerosene vapour, and is true although the concentrations attained are far below the saturation concentration of kerosene vapour in air. An investigation has been carried out on various aspects of the properties and behaviour of insecticidal mists and will form the subject of a later paper in this series. Meanwhile it must suffice to consider only the bearing this factor has on the bio-assay of anti-mosquito sprays in the spray chamber.

Since the volume dosage level of spray utilised in the spray chamber was low, and there was an interval of four minutes between spraying and the time at which the insects were exposed there was plenty of opportunity for effects associated with differences in volatilities between sprays to become apparent. The most important case encountered was in connection with the addition of so-called activators or adjuvants (*e.g.*, Isobutylundecylenamide and Sesame oil) to pyrethrum sprays. It was found that the increase in kill observed in the presence of these substances was the expression of a combined increase in particle size, which led to more ready impaction of the spray droplets on the insects, and the specific activating effect of the adjuvant operating in an unexplained manner. The increase in kill attributable to the increased particle size could be brought about by the addition of about 5 per cent. volume of a non-volatile ingredient such as high vacuum pump oil or medicinal paraffin to the spray, but the increment observed was always less than that induced by a corresponding amount of activator having the dual action as Tables III *a* and *b* show. When examining the effects of activators by the suggested method it is therefore necessary to compare the activated spray, not with the straight pyrethrum spray, but with a spray containing the same volume of added non-volatile ingredient such as one of the oils mentioned.

TABLE IIIa.

The effect of adding a non-volatile mineral oil, Sesame oil free from Sesamin (the activating ingredient), and Sesame oil to a Pyrethrum Spray under standard testing conditions.

Insecticide	24-hr. % kill	Average % kill in 24-hrs.	Average angle ±1·1°
Pyrethrins 0·05% w/v	19, 16, 20, 25	20	27
Pyrethrins 0·10% w/v	59, 61, 58, 62	60	51
Pyrethrins 0·05% w/v High vacuum pump oil 5·0% v/v	83, 77, 75, 78	78	62
Pyrethrins 0·05% w/v Desesaminised sesame oil 5·0% v/v	84, 83, 81, 77	81	64
Pyrethrins 0·05% w/v Sesame oil 5·0% v/v	96, 95, 98, 97	96	79

TABLE IIIb.

The effect of adding a non-volatile mineral oil and isobutylundecylenamide to a Pyrethrum Spray under standard testing conditions.

Insecticide	24-hr. % kill	Average % kill in 24-hrs.	Average angle ±1·9°
Pyrethrins 0·05% w/v	27, 16, 28, 21	25	29
Pyrethrins 0·10% w/v	65, 67, 80, 69	70	57
Pyrethrins 0·05% w/v High vacuum pump oil 2·0 %v/v	68, 75, 83, 85	78	62
Pyrethrins 0·05% w/v Isobutylundecylenamide 2·0% v/v	97, 98, 97, 98	98	81

The pronounced effect of increasing the particle size of the mist by adding a non-volatile ingredient to the spray and the relatively smaller additional effect attributable to the specific activating properties of adjuvants will be noted. The former effect only becomes apparent when differences in particle size between two sprays become established while the specific activating effect of sesame oil and isobutylundecylenamide was obtained under all circumstances that have been investigated.

The Effect of varying certain of the Standard Testing Conditions.

In order to understand the properties of the spray chamber more completely, experiments were carried out in which certain of the Standard Testing Conditions were altered. In this way information was obtained concerning the relative importance of the various standardised conditions, and the effect that small departures from them in the course of routine work would be likely to have on the final results recorded in a test.

(*a*) *Temperature.*

As has already been stated, the temperature normally employed corresponded with that of the breeding and recovery rooms so that it was unnecessary to condition the insects to a changed temperature before carrying out the spray tests. The temperature concerned was 28°C., but for the sake of these experiments temperatures of 20° and 30°C. were chosen for the exposures. It may be inferred from work on other insects (Mellanby, 1939) that conditioning for activity at a new temperature within the range considered will be very rapid. The insects exposed at 30°C. were, therefore, transferred directly to the spray chamber without preconditioning whilst those treated at 20°C. were given a 10-15 minute conditioning period. In other respects standard conditions were maintained and all insects were allowed to recover at 28°C.

TABLE IV.

Effect of altering the temperature at which the insects were exposed from 20° to 30° C.

Temperature ° C.	Average 24-hr. % kill		Average angle ±1·2°
	Culture 1	Culture 2	
20	43	27	35·8
30	65	46	48·0

Spray solution 0·7 c.c. Official Test Insecticide (Pyrethrins 0·10% w/v). Otherwise standard testing conditions.

Unfortunately the two cultures showed a resistance rather dissimilar from the pyrethrum spray, but it can be seen in both cases that a 10°C. drop in temperature reduced the observed kill by about 20 per cent. Although other explanations are not excluded, it seems probable that this decrease in kill merely indicates that the insects exposed at 20°C. accumulated less spray because they were less active than those exposed at 30°C. By applying the insecticide by the impaction method, described in a later paper, this question could be easily settled. It may be concluded that close control of temperature is an important feature in carrying out bio-assay tests with *Aëdes aegypti*.

(*b*) *Humidity.*

As is well known, it is almost always necessary to control the humidity of insect breeding rooms if uniform and healthy cultures are required (Mayne, 1930; Lewis, 1933). In the Peet-Grady method the humidity in the spray chamber is also controlled) and this would seem to be advisable since mosquitos commonly show behaviour reactions to humidity (Lewis, 1933). The latter consideration suggests a reason why humidity control might be necessary in the absence of any effect on the level of susceptibility to poisons associated with short exposures to unfavourable humidities. Of course if aqueous base sprays were being examined it would be obviously desirable to control the humidity of the atmosphere since this would influence the rate of droplet evaporation, and so the period of suspension of the spray in the atmosphere. The latter point was investigated by Potter and Hocking (1939) who showed that the insecticidal ingredients of aqueous sprays remained in suspension much longer when they had been introduced into a dry than into a moist atmosphere.

With the above considerations in mind the decision was taken to control the humidity of the spray chamber in all routine tests. However, when experimental sprayings with a pyrethrum spray were carried out, using *Aëdes aegypti* as the test insect, no difference could be detected between the results obtained at 40 and 80 per cent. relative humidity. For this test the insects were removed from their breeding room, which was maintained at approximately 70 per cent. R.H., and inserted into the spray cabinet without previous conditioning to the lower humidity employed. The results obtained are set out in Table V.

Unless, therefore, the position is different with other insecticides it is unnecessary to control the humidity in the spray chamber, at any rate within the region 40-80 per cent. R.H.

TABLE V.

Effect of altering the humidity of the spray chamber atmosphere from 40 to 80% R.H. Temperature 28°C.

Humidity of exposure % R.H.	24-hr. % kill	Average % kill in 24-hrs.	Average angle ±0·8°
40	75, 77, 73, 75	75	60
80	77, 78, 72, 72	75	60

Spray 0·7-c.c. of Official Test Insecticide (Pyrethrins 0·1% w/v).

(*c*) *Duration of Exposure to the Mist.*

Following the conditions laid down in the Peet-Grady test, it was decided to expose the insects to the spray mist for a period of ten minutes. This interval allows a reasonable time for knockdown to occur without being so long as to impede the progress of the day's testing. In general it seemed to be a very satisfactory exposure. Since, however, the majority of the insecticidal dose is picked up during flight, nothing is gained by continuing the exposure after knockdown has occurred.

An example of an experiment to investigate the influence of the duration of exposure on final kill recorded is given in Table VI. The insects were exposed to the O.T.I. spray under standard conditions. Under these circumstances there is no knockdown after two minutes exposure, about 25 per cent. after four minutes exposure and about 95 per cent. after eight minutes. It will be noted that although the knockdown is not complete until after the eighth minute extending the exposure beyond the fifth minute contributes but little to the observed kill. The total flying time and so the quantity of insecticide accumulated by the fraction of the insects which resist knockdown beyond five minutes must represent only a negligible part of the total dose accumulated by the group exposed.

Table VI.

Effect of altering the duration of the exposure to an insecticidal mist of 0·7 c.c. of O.T.I. under otherwise standard test conditions.

Duration of exposure (min.)	24-hr. % kill			Average % kill in 24-hrs.	Average angle ±1·1°
2	42	43	45	44	41·0
5	60	69	66	65	53·7
10	64	67	71	67	55·0

(*d*) *Time of Insertions varied.*

It has already been stated that under the standard testing conditions adopted the insects were not inserted until four minutes after the time at which spraying was commenced. The majority of the standard dose of 0·7 c.c. was injected in under 15 seconds, but the compressed air was always allowed to flow for 25 seconds. The original reasons for waiting four minutes were twofold: firstly it was thought that it would give an opportunity for the coarser droplets to settle out and so avoid variable results due to the chance impaction of these droplets on certain of the insects which would make the dose accumulated by individuals rather variable—as has been shown to occur in the Peet-Grady test (Murray 1940). Secondly at this time little was known about the method by which the insecticidal dose was acquired and it seemed possible that an appreciable amount might be accumulated from the substratum on which the larger droplets had fallen. This again is known to happen in the Peet-Grady test since the percentage kills recorded with and without absorbent paper on the floor are appreciably different, being lower when paper is employed by some 20 per cent. Delaying the insertion of the insect exposure cages until after deposition had occurred would minimise this effect. It may, however, be argued that the delay is artificial in the sense that it would not occur in practical application of the sprays and might produce discrepancies between the results observed in the cabinet and those obtained in practice. The most obvious cause of such discrepancies would be that associated with the different volatility characteristics of sprays which are being compared, since the delay would allow the maximum opportunity for particle size differences to become established as a result of different evaporation rates of the droplets. Two rather distinct aspects of the situation were investigated: firstly the influence of varying periods of delay on the rate of decline of insecticidal efficiency of pyrethrum sprays with and without 5 per cent. of added non-volatile matter, and secondly the relative insecticidal efficiency of the same sprays at different periods after application. The results obtained are set out in Tables VII, VIII and IX.

Table VII.

Effect of varying the time of introducing the insects into an atmosphere sprayed with O.T.I. containing no added non-volatile material.

Time interval before exposure (min.)	Average 24-hr. % kill		Average angle ±0·8°
	Culture 1	Culture 2	
0·5	80	86	65·5
2·0	65	75	57·0
4·0	61	70	54·0
10·0	42	57	44·8

0·7 c.c. of spray under standard conditions.

TABLE VIII.

Effect of varying the time of introducing the insects into an atmosphere sprayed with 40% O.T.I. + 5% high vacuum oil.

Time interval before exposure (min.)	24-hr. % kill					Average 24-hr. % kill	Average angle ±1·7°
0·5	79	76	81	79	80	79	63
2·0	64	68	78	65	57	67	55
4·0	46	59	70	53	53	56	49
10·0	35	33	31	44	36	36	37

0·7 c.c. of spray under standard conditions.

TABLE IX.

Comparison between the effect of pyrethrum sprays with and without added non-volatile material made on insects inserted into cabinet before spraying and four minutes after spraying.

Insecticide sprayed	Insects inserted before spraying		Insects inserted after spraying	
	Average 24-hr. % kill	Average angle ±1·2	Average 24-hr. % kill	Average angle ±1·1
Pyrethrins 0·05% w/v	34	35	12	20
Pyrethrins 0·05% w/v ... ... High vacuum oil 5·0% v/v ...	78	62	55	48
Pyrethrins 0·05% w/v ... ... IN 930 2% v/v	95	78	78	62

0·7 c.c. injected under standard conditions. Each average is based on two determinations.

It may be concluded from these three tables that the practice of waiting for four minutes before introducing the insects into the spray chamber merely leads to a lower percentage kill without appreciably affecting the relative order of toxicity of the insecticides. So far as the consistency of the results is concerned, however, there appears to be no advantage gained by the delay.

(*e*) *Caged and Uncaged Insects.*

In all the ordinary tests described in this paper the insects were introduced into the spray chamber enclosed in the insect exposure cages which have already been described. This practice was adopted in order to avoid the difficult task of collecting any insects which remained unparalysed in the spray chamber at the end of the ten minutes' exposure. In the case of DDT sprays, for example, none of the insects was paralysed after this interval. By caging the insects they were also prevented from coming into contact with any part of the chamber floor or walls which might have become rather heavily contaminated with the spray.

The practice of using caged insects, however, is artificial. The near presence of the walls allows the insect to alight after flying but a short distance through the mist, and so reduces the dose accumulated. Furthermore it tends in a spray chamber to prolong the interval between the formation of the spray droplet and its contact with the insect. With caged insects at a distance below the point of injection of the spray this interval must be on the average greater than when the insects are inserted free in the cabinet before spraying. When comparing sprays of different volatilities this is an important point, since the slightly longer interval between the formation of the droplet and its impaction with the insect allows more time for droplet size differences between the two sprays to become established. The results given in Tables X (*a* and *b*) show this effect. It will be noted that with caged insects addition of a non-volatile constituent to the spray increased the kill to a marked extent (44 and 33 per cent., Tables X *a* and *b*, respectively) while when the insects are flying free in the cabinet the increment in the observed kill amounted to 11 and 19 per cent., respectively. As would be expected from the preceding discussion the relative efficiency of sprays containing high vacuum pump oil and those containing an activator such as isobutylundecylenamide (IN 930) or sesame oil remains essentially the same whether the comparison is made on caged or on free-flying insects.

TABLE Xa.

Comparison of the efficiency of various sprays to caged and free-flying insects.

Insects caged in cabinet			Insects free in cabinet		
Insecticide	Average 24-hr. % kill	Average angle ± 1·2	Insecticide	Average 24-hr. % kill	Average angle ± 1·7
Pyrethrins 0·05% w/v	34	35	Pyrethrins 0·03% w/w	73	59
Pyrethrins 0·05% w/v High Vacuum Oil 2% v/v	—	-	Pyrethrins 0·03% w/w High Vacuum Oil 2·0% v/v	81	64
Pyrethrins 0·05% w/v High Vacuum Oil 5·0% v/v	78	62	Pyrethrins 0·03% w/v High Vacuum Oil 5·0% v/v	84	66
Pyrethrins 0·05% w/v Isobutylundecylenamide 2·0% v/v	95	78	Pyrethrins 0·03% w/v IN 930 2·0% v/v ...	100	90

Volume of spray was 0·7 c.c. injected under standard conditions. There was paper on the floor of the cabinet. Each average is based on two determinations.

TABLE Xb.

Comparison of the efficiency of various sprays to caged and free-flying insects.

Insecticide	Insects caged in cabinet		Insects free in cabinet	
	Average 24-hr. % kill	Average angle ± 1·3	Average 24-hr. % kill	Average angle ± 0·7
Pyrethrins 0·04% w/v	35	36	65	54
Pyrethrins 0·04% w/v ... ... High Vacuum Oil 5·0% v/v ...	68	55	84	66
Pyrethrins 0·04% w/v ... ... Sesame Oil 5·0% v/v	87	69	98	82

Volume of spray was 0·7 c.c. injected under standard conditions. There was paper on the floor of the cabinet. Each average is based on three determinations.

Summary and Conclusions.

The considerations affecting the design of a spray testing chamber are discussed, and a description is given of equipment specially intended for use with mosquitos as the test insect. In essentials the apparatus consisted of a metal chamber surrounded by a " Masonite " cabinet with an air space in between. In this space air, at a constant temperature, was circulated around the outer face of the inner metal chamber and so controlled the temperature of the spray chamber. The cabinet was fitted with lights; wet and dry bulb thermometers to check the humidity, which was controlled by blowing in steam; a fan to circulate the air; a spray gun; four ports through which the insect exposure cages were introduced into the chamber; a shelf to carry these cages; and an exhaust and an intake port to allow the mist to be removed at the conclusion of the test. Finally, there was a door on one side allowing access to the interior. It will be noted that the insects were introduced into the spray chamber in cages and not allowed to fly freely. This greatly facilitated the collection of insects at the conclusion of the test. Under the routine testing conditions adopted the insects were not introduced until four minutes had elapsed after spraying. They were then exposed for ten minutes and afterwards transferred to clean recovery cages.

The practice of caging the insects and placing them on a shelf opposite a window within the spray chamber permitted the insects to be closely observed and the rate of paralysis (knockdown) to be followed. In general, however, the rate of knockdown, when it occurs, was not so sensitive a method of comparing insecticidal efficiency as the twenty-four hour percentage kill.

In practice the apparatus was found to give satisfactory results. It permitted accurate comparisons to be made between different strengths of a given insecticidal solution, but care had to be taken to ensure that the non-volatile content of the sprays being compared for toxicity was essentially similar. When this was not so, other things being equal, the spray which produced the less volatile mist (*i.e.*, the larger particle size) gave the higher kill. When working on activators, which are usually non-volatile materials, it was therefore necessary to add an equivalent quantity of, say, high vacuum pump oil to the control spray before making the comparison. Examples of the application of the method of pyrethrum, DDT, and activated sprays are given.

The set of standard conditions chosen for the routine testing procedure were sometimes rather arbitrarily fixed but usually with due reference to the requirements of the insects or to practical testing conditions. Since two of the conditions chosen, *i.e.*, the use of caged insects and exposure after an interval of four minutes after spraying, were rather artificial from the point of view of practice and might conceivably have led to conclusions inapplicable to practical conditions, the effect of modifying certain of the standard procedures was investigated. The results of these experiments are fully described in the text. It was concluded that temperature influenced the level of kill recorded considerably, the kill being lower when the temperature of the spray chamber was dropped 10°C. Humidity seemed to have little or no effect within the range 40-80 per cent. R.H. Increasing the interval at which the insects were inserted after spraying from 0 to 10 minutes affected the level of kill without influencing the comparative efficiency of the insecticides examined. On the other hand caging the insects had a pronounced effect on the comparative efficiency of pyrethrin sprays with and without added non-volatile material. This was thought to be due to the delay in access of the spray droplets to the caged insects which permitted a sufficient interval for the differences in particle size to become established. With caged insects inserted before spraying, therefore, the biological efficiency of a pyrethrin spray without added non-volatile material is much lower than when some such substance as high vacuum pump oil is added, whereas this difference is much smaller when the insects are exposed free in the cabinet (Table X).

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References.

Allen, T. C., Dicke, R. J. & Brooks, J. W. (1943). Rapid insecticide testing settling mist on houseflies.—Soap, **19**, no. 4, pp. 94-96.

Bliss, C. I. (1938). The transformation of percentages for the use in the analysis of variance.—Ohio J. Sci., **38**, pp. 9-12.

Campbell, F. L. & Sullivan, W. M. (1938). Testing fly sprays: a metal turntable method for comparative tests of liquid spray contact insecticides.—Soap, **14**, no. 6, pp. 119-125, 149.

David, W. A. L., Bracey, P. & Harvey, A. (1944). Equipment and method employed in breeding *Aëdes aegypti* L. for the biological assay of insecticides.—Bull. ent. Res., **35**, pp. 227-230.

Kearns, C. W. & March, R. B. (1943). Small chamber method for testing effectiveness of insecticides against houseflies.—Soap, **19**, No. 2, pp. 101, 103-104, 128.

Leeson, H. S. (1939). Longevity of *Anopheles maculipennis* race *atroparvus* under controlled temperature and humidity.—Bull. ent. Res., **30**, pp. 295-301.

Lewis, D. J. (1933). Observations on *Aëdes aegypti* L. under controlled atmospheric conditions.—Bull. ent. Res., **24**, pp. 363-372.

Mayne, B. (1930). A study of the influence of relative humidity on the life and infectibility of the mosquito.—Indian J. med. Res., **17**, pp. 1119-1137.

Mellanby, K. (1939). Low temperature and insect activity.—Proc. roy. Soc., (B) **127**, pp. 473-487.

Murray, C. A. (1940). A fundamental error in the Peet-Grady method.—Soap, **16**, no. 6, pp. 111, 113, 115, 117, 119, 125.

Peet, C. H. & Grady, A. G. (1928). Studies on insecticidal activity. I. Testing insecticides against flies.—J. econ. Ent., **21**, pp. 612-617.

Potter, C. & Hocking, K. S. (1939). An apparatus for testing and comparing the biological action of insecticides on flying insects and a method for sampling the concentration of atomised insecticide.—Ann. appl. Biol., **26**, pp. 348-364.

MOONLIGHT AND HOUSE-HAUNTING HABITS OF FEMALE ANOPHELINES IN WEST AFRICA.

By Major C. R. Ribbands, *R.A.M.C.* YP

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Introduction.

Regular spraying of native dwellings in order to kill adult Anophelines has been shown to be a useful anti-malaria measure both in Africa (*e.g.*, in Natal, by Ross, 1936) and elsewhere.

This measure was introduced into Sierra Leone in 1940 by Mr. P. Slater, Malaria and Sanitary Superintendent, as part of an anti-malaria scheme for West Freetown and district. For its successful operation it was important to know as much as possible about the house-haunting habits of the Anophelines concerned, and for this reason the experiments now described were conducted.

The very small costs were defrayed from Army funds—the experiments in Sierra Leone by a grant from the Wilberforce Sanitation Scheme, through the good offices of Dr. G. Waller, Assistant Director of Civil Medical Services, and Mr. Slater, and the experiments in the Gold Coast with funds provided through Lt.-Col. G. K. Fulton, Assistant Director of Hygiene, West African Command. I am indebted to Mr. Slater for his continued interest and stimulating criticism.

Methods.

The experiments were conducted at Aberdeen, near Freetown, Sierra Leone, and at Krabonekrom, near Sekondi, Gold Coast. In both cases several similar huts were used, and selected native labourers were paid to sleep in them. Preliminary experiments had shown that there were no significant differences in the relative attractiveness to mosquitos between similar huts in the same situation, but that considerable differences existed between the relative attractiveness of different individuals. In all the experiments now described any differences in the relative attractiveness of either the huts or the natives have been cancelled by a suitable rotation of catching and duties. This paper deals only with female Anophelines; the behaviour of the males will be discussed elsewhere.

(*a*) *The experimental area at Aberdeen, Sierra Leone.*

The first experiments were made at Aberdeen Creek, near Freetown, Sierra Leone, from January to September, 1941. For a full description of the breeding area and a map of the district, reference should be made to a previous publication (Ribbands, 1944, *a*). Experimental huts, whose relative positions are shown in fig. 1, were built within a few yards of the edge of the breeding area, and half a mile from the nearest native inhabitants, who lived in the village of Aberdeen. Huts C and D were erected in January, 1941, and were shimbecs built of rough raffia palm thatch, on a framework of bushsticks, and lined with native rush matting. The size of these shimbecs was 10 ft. × 6 ft., and they were 6 ft. high at the eaves. The entrances, 2 ft. 6 ins. wide, were imperfectly coverable by " doors " made of loosely-woven raffia palm. The other huts were erected in

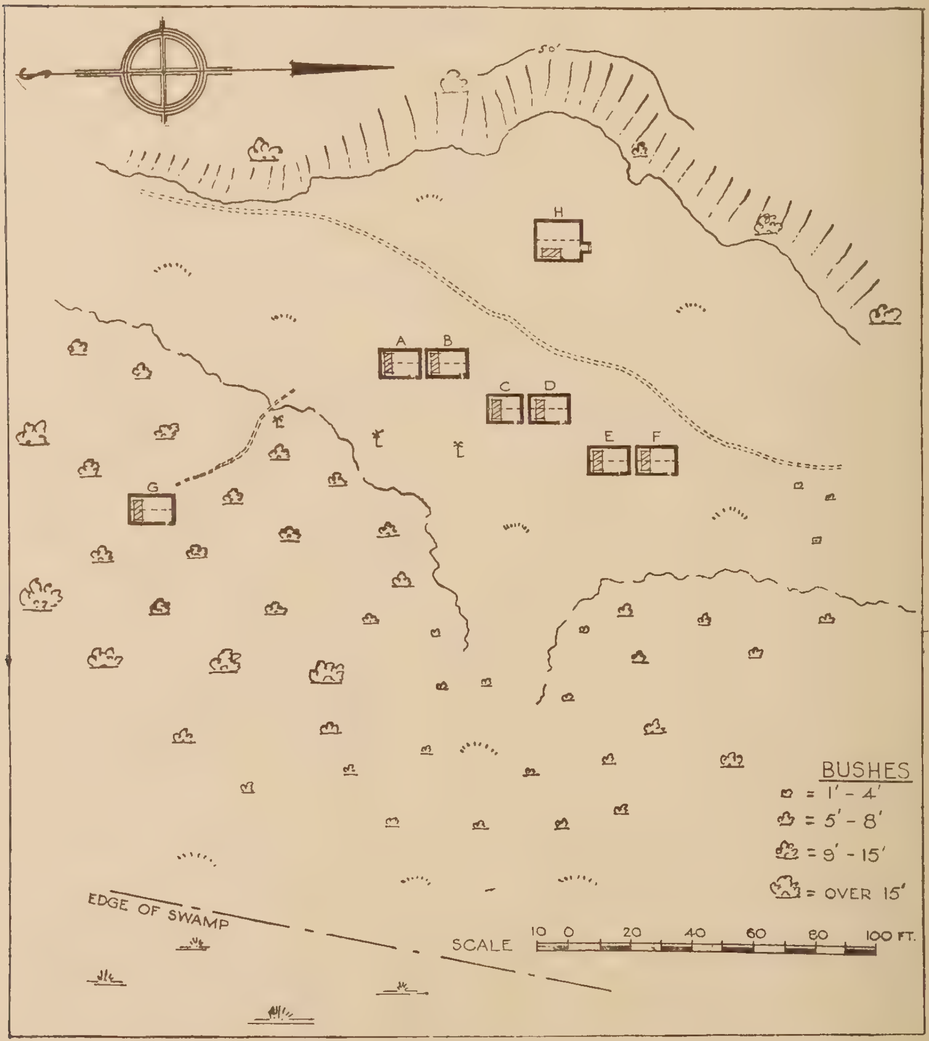

FIG. 1.—Aberdeen experimental area.

August, to the same plan, except that they were covered externally with flattened oil drums instead of raffia palm thatch; at the same time huts C and D were re-covered with flattened oil drums too—this material being more weatherproof than palm. The entrances were now coverable with a blind made of rush matting. Huts A-F were used for the experiments described, and I occupied hut H in order to supervise them.

Most of the breeding area was within tide limits and bred *Anopheles melas*, but there was a freshwater seepage area along its upper edge, and this produced *A. gambiae*. No simple method of distinguishing between adults of these two species was known, and so deductions had to be made from palp distinctions (Ribbands, 1944, *b*). In the dry season, from March to May inclusive, the palps of nearly 40 per cent. of the catches were "*melas*-banded", and at this time the freshwater seepages were dry and the population must have consisted almost entirely of *A. melas*. From mid-August until end-September, when most of the experiments described herein were conducted, 196 out of 608, or 32 per cent. of the catch, had "*melas*-banded" palps. This high proportion indicates that the Anopheline population throughout these experiments was predominantly *A. melas*.

(*b*) *The experimental area at Krabonekrom, Gold Coast.*

These experiments were made between 1st January and 16th March, 1942, as a by-product of other experiments which will be described elsewhere. Krabonekrom was a small African village, situated a few miles west of Sekondi, Gold Coast. The inhabitants were evicted and all but three of the huts were pulled down. These three huts were retained for experimental purposes. They were built of mud, on a framework of bushsticks and bamboo, and roofed with iron. Hut X contained a row of four rooms and hut Y a row of three rooms. These rooms were each approximately 20 ft. × 15 ft., 7 ft. high at the eaves and 10 ft. high at the centre; their end and partition walls were continued to the roof, so that the rooms were completely separated, but there was a gap about 9 ins. wide, native style, between the side walls and the eaves. Each room of hut X had an entrance, 2 ft. 6 ins. × 6 ft., facing west, and coverable by a blind made of native rush matting, and these four identical rooms were used for all the experiments on the time of night entry. There were communicating doors between the three rooms of hut Y, with an external door to the central room; the central room was never used, and the end rooms were used alternately for sleeping the three men required as a control for the experiment on time of entry and the one man who slept alone. Hut Z, 15 yards away, was occupied by myself in order that I might be able to maintain continual supervision.

The nearest other inhabitants were three natives who occupied another experimental hut 140 yards away, and there were no other inhabitants within 440 yards. The nearest breeding place was a large swamp which was a minimum distance of 880 yards away, in an easterly direction. The weedy edges of the nearer end of this swamp bred *A. funestus* in numbers; the lower half of the swamp was open and bred *A. gambiae* along its muddy edges. Some brackish water entered the lower end of the swamp through a culvert, and the continuation of the swamp on the far side of the culvert was brackish. But few *A. melas* were present, and of 1,007 identified *A. gambiae* caught during these experiments only one had "*melas*-banded" palps, so that this population can be considered to have consisted of *A. gambiae* only.

(*c*) *Method of catching the mosquitos.*

The mosquitos were always collected by the same method. The mud floor was covered with sheets before the occupant entered. When the mosquitos were to be collected, the door was closed and the room was then thoroughly flitted with a pyrethrum-in-kerosene mixture (1:64). Five minutes later the mosquitos were collected from the sheets; in the daytime the sheets were carefully picked up and taken into the open to be examined, and the whole process could be done efficiently by native labourers under supervision, but at night both spraying and catching were done by the writer, who searched the sheets, using a torch.

This method was used in preference to hand-catching, for the reasons outlined in Appendix 1. Haddow (1942) has criticised the spray method on the grounds that the insecticide might soon make the hut untenable for mosquitos, and that it is unsuitable for night work. Any repellent effect can be neglected when considering the present experiments, because if present it was constant throughout; thorough access of air and sunlight every day probably reduced any such effect considerably. The disadvantages of the method for night work were overcome by using a series of identical huts, and shifting the native to a fresh hut after each catch. I consider that this provision makes the spray method more efficient than hand-catching by night, as it is by day, because all the operations can be carried out by the experimenter and there is little chance of variation in the efficiency of the catching medium with the quantity of light available or the activity of either the mosquitos or the native catching-boy.

(*d*) *The times of sunrise, sunset, and twilight.*

The times given in this paper refer to local time. At Aberdeen local time was 40 minutes behind G.M.T. and at Krabonekrom is was G.M.T. The time at which Anophelines commence flighting is still unknown, and it is therefore necessary to give particulars of time of sunset and the various stages of twilight. These particulars, compiled from *The Nautical Almanac* and converted to local time, are given in Table I.

TABLE I.

Average times of sunset, sunrise and twilight.

	Aberdeen 27th August-21st September, 1941	Krabonekrom 30th January-10th March, 1942
Sunset to sunrise	5.25 p.m.-5.10 a.m.	6.20 p.m.-6.30 a.m.
Civil twilight	5.40 p.m.-4.45 a.m.	6.40 p.m.-6.05 a.m.
Nautical twilight ...	6.05 p.m.-4.25 a.m.	7.00 p.m.-5.45 a.m.
Astronomical twilight ...	6.35 p.m.-4.00 a.m.	7.30 p.m.-5.10 a.m.

The Anopheline Population in empty Huts.

At Aberdeen, on ten occasions between 29th August and 8th September, an empty hut was sprayed at 10 p.m. Only 2 unfed ♀ *A. melas* were caught, but a hut containing one native, and sprayed on the same ten occasions at the same time, produced 66 ♀ *A. melas;* on 52 occasions between 17th August and 14th September empty huts were sprayed at 6.30 a.m. and the total Anopheline catch was 1 ♂ and 1 unfed ♀ *A. melas*, although 863 ♀ *A. melas* (= 16·5 per room) were obtained from the same number of occupied huts at the same times.

At Krabonekrom I was unable to conduct experiments to indicate the number of mosquitos resting in unoccupied huts, but considerable indirect evidence led me to conclude that the number was equally insignificant. Results of catches in empty rooms are clearest when the catch in the empty rooms is expressed as a percentage of the catch in similar rooms occupied by one inhabitant. At Aberdeen for the morning catch of ♀ *A. melas* this figure was 0·1 per cent. whereas Haddow (1942) found in Kenya 6·3 per cent. ♀ *A. gambiae* and 7·8 per cent. ♀ *A. funestus* under similar conditions, but using hand catching; in Brazil Causey *et al.* (1943) obtained 1 per cent. ♀ *A. gambiae.* Night catches at Aberdeen yielded 3 per cent. ♀ *A. melas*, whereas Haddow obtained 23·8 per cent. ♀ *A. gambiae* and 30 per cent. ♀ *A. funestus.*

These results agree in that they show that in empty huts many more female Anophelines were obtained during night catches: this affords strong presumptive evidence that huts are not preferred resting places for unfed female Anophelines, which enter to search for food and usually depart if they fail to find it.

The percentage of females which are blood-fed should also bear a relation to the proportion of females entering for food and those entering merely for shelter, and whereas Haddow found that in day catches 23 per cent. ♀ *A. gambiae* and 12 per cent. ♀ *A. funestus* remained unfed, my results showed that in Krabonekrom day catches only 4 per cent. ♀ *A. gambiae* and 3 per cent. ♀ *A. funestus* were unfed, and in Aberdeen only 1 per cent. ♀ *A. melas.*

This confirms the conclusion that few female Anophelines entered either Krabonekrom or Aberdeen huts for shelter only. The difference between the results from West Africa and those from Kenya might be attributed to a repellent effect following the continued use of the pyrethrum-in-kerosene spray in the West African experiments, but in the same localities under conditions where this effect could not operate the proportion of freshly blood-fed females in house catches was equally high, and I therefore think that this difference may be due to a difference in climate, and especially in humidity, which has made outdoor conditions relatively less favourable for shelter in Kenya. Whatever its cause, the virtual absence of female Anophelines in unoccupied huts has made the series of night catches possible, using spray without the necessity for special mosquito-proofed huts.

The Time of Exit.

(*a*) *The proportion of mosquitos that remained after dawn.*

There was no simple direct method of determining the number of Anophelines which entered and left the huts the same night, but it was considered that if any considerable proportion of the mosquito entrants normally did so, the sum total of the catches made at intervals through the night and after dawn would exceed the total of a single catch made under the same conditions after dawn, since some of the mosquitos which would have left by dawn would be caught in the night catches.

The results of comparing the all-night catches of *A. funestus, A. gambiae* and *A. melas* with the equivalent single morning catches, both at Aberdeen and Krabonekrom, are given in Table II, and compared with the similar catches obtained at Kisumu, Kenya, by Haddow (1942). In all cases, with the possible exception of the *A. gambiae* at Kisumu, the discrepancies between the day and night catches are not significant, and when all five results are added, a total of 3,667 ♀ Anophelines were caught in the night catches, and 3,577 in the equivalent day catches, a difference of only 3 per cent. This small discrepancy indicates that when these species of Anophelines feed in suitable houses they nearly always remain in them until after dawn.

TABLE II.

Comparison of night and day catches.

	Species	Locality	No. of natives employed	No. of night catches	No. of ♀♀ caught		Ratio : Day to night catch
					Night	Day	
	A. funestus ...	Krabonekrom ...	3	33	775	713	92%
(*a*)	*A. funestus* ...	Kisumu (Haddow) ...	1	53	1,311	1,491	114%
	A. gambiae ...	Krabonekrom ...	3	33	54	75	139%
(*a*)	*A. gambiae* ...	Kisumu (Haddow) ...	1	53	974	664	68%
(*b*)	*A. melas* ...	Aberdeen	1	21	553	634	115%
	TOTAL, all species				3,667	3,577	97%

Notes : (*a*) Haddow's day catches were made on different days from the night catches. The day catches are based on results for 320 days.
(*b*) Two undisturbed controls were used for the day catches. The average is given.

This conclusion may be open to question because in my experiments the human bait changed rooms three times during each evening, and it is possible that after each change of room there was an appreciable period before the inhabitants had made the room attractive to mosquitos. This possibility did not arise in Haddow's experiments, where the inhabitants remained in one room and results are based on hourly hand catches. I think that the close similarity between the results from both series of experiments suggests that there is no appreciable delay before the inhabitants attract mosquitos to any room they occupy, and indicates that in both places the fed Anophelines remained until dawn.

(*b*) *The proportion of A. melas that left during the day.*

These experiments were made at Aberdeen, between 21st June and 26th August, in huts C and D, which were still palm-thatched. Two natives were employed, one to sleep in each hut. The doors of both huts were left open through the night, and when the natives left the huts at about 6 a.m. the mosquitos were collected from one of the huts, but they were not collected from the second hut until 2 p.m.

On 36 days between 21st June and 26th July the " door " of the second hut, this very ill-fitting contraption of loosely-woven palm leaves, was kept closed from 6 a.m. until the mosquitos were collected at 2 p.m. During this period, 706 ♀ *A. melas* were obtained in the 6 a.m. catch, and 711 in the 2 p.m. catch—the catches were equal on three days, the early catch was greater on 17 days and the late catch greater on 16 days. Hence it may be concluded that under these favourable conditions, with little light or ventilation, *A. melas* showed no tendency to leave the hut during the daytime.

On 23 days between 30th July and 26th August when the " door " was left open all day in both huts, so that there was an opening 2 ft. 6 ins. × 5 ft. through which ample light and breeze entered (more than in most native huts) 375 ♀ *A. melas* were obtained in the 6 a.m. catch, and 272 in the 2 p.m. catch. The early catch was larger on 20 occasions, and the late catch only twice. Hence under these conditions of light and ventilation about 25 per cent. of the mosquitos left the hut between 6 a.m. and 2 p.m.

Conclusions concerning time of exit.

Results from Aberdeen and Krabonekrom lead to the conclusion that all or nearly all the female Anophelines, whether *A. gambiae, A. melas* or *A. funestus*, which fed in the native huts stayed there until early next morning. Haddow (1942) came to the same conclusion after a similar analysis of *A. gambiae* and *A. funestus* behaviour in Kenya.

Aberdeen results also show that under favourable conditions, with little light or ventilation, female *A. melas* showed no tendency to leave the hut during the daytime, but that when doors were left open to provide plenty of light and ventilation some mosquitos were disturbed and about 25 per cent. left the house before 2 p.m. The exit of mosquitos from unsuitable (well-lit and well-ventilated) quarters would account for the discovery of fed ♀ *A. melas* (referred to as *A. gambiae*) in bushes outside *European* bungalows in Freetown (Blacklock & Wilson, 1941), and might be partly responsible for the finding of much greater numbers of *A. gambiae* in ill-lit, badly ventilated (native style) houses in Freetown than in adjacent, more open, airy (Creole style) houses (Gordon *et al.*, 1932)—though differences in the quantity and quality of the human population probably played a greater part in this latter case. However, light and well-ventilated quarters are infrequent in African life, and it may be presumed that these circumstances are exceptional and that most Anophelines remain undisturbed in their household resting places throughout the day. At least 5 per cent. of West African ♀ *A. gambiae* seem to remain throughout the following night and day as well (Gordon *et al.*, *ibid.*), and recent results indicate that up to 20 per cent. of Brazilian *A. gambiae* remain within the same house more than 24 hours (Causey *et al.*, 1943).

Influence of Moonlight on Time of Entry.

(*a*) *Relation between time of entry of ♀ A. funestus and time of moonlight.*

Seven natives were employed, in rotation, for these experiments, which were conducted at Krabonekrom. The natives retired at 6 p.m. and each night three of them slept undisturbed in one room in hut Y, and three slept in one room in hut X. These latter were awakened at 8 p.m. and sent into another room in hut Y, and this process was repeated at 10 p.m. and midnight. I supervised the natives from 6 p.m. onwards, and sprayed each hut and collected the mosquitos from it as soon as the natives left it in the evening. The natives rose and left their huts soon after sunrise, and the morning collections from the huts of both the disturbed and the undisturbed natives were made at 7.30 a.m. under supervision of a competent British N.C.O.

The 8 p.m. catch was at approximately 1⅔ hours after sunset (*see* Table I). The morning catch was not made until 1 hour after sunrise, though the natives vacated the huts at or about sunrise.

The number of Anophelines obtained varied very considerably from day to day, the maximum and minimum catches from one room being 73 and 2, respectively. Some of the causes of the variation in the size of this and other Anopheline populations have been discussed elsewhere (Ribbands, 1944 *a*); one consequence of this variation is that when catches of different days are compared the effects of the variation must be eliminated by the use of percentages instead of absolute numbers.

The results are recorded in Table III, which shows both the number and the percentage of ♀ *A. funestus* caught in each collection for each of 33 days between 30th January and 10th March, 1942; this table also records, from data compiled from *The Nautical Almanac*, 1942, both the times of moonrise and moonset and the phase of the moon on each of these days in this locality.

When the results were being collected, the average time of entry varied very noticeably from week to week, and this variation was observed to be related to a variation in the time of moonlight.

TABLE III.

Entry of ♀ *A. funestus.*

Date 1942	No. of *A. funestus* caught				Percentage of *A. funestus* at each period				Time of moonlight	Phase of moon	No. of *A. funestus* in undisturbed control
	8 p.m.	10 p.m.	midnight	7 a.m.	8 p.m.	10 p.m.	midnight	7 a.m.			
Jan.											
30	1	1	3	7	8	8	25	58	Until 5.27 a.m. ...	94	37
31	6	1	3	14	25	4	12	58	Until 6.15 a.m. ...	98	1
Feb.											
3	7	21	12	8	15	44	25	17	From 8.12 p.m. ...	97	87
4	1	25	21	26	1	34	29	36	From 9.02 p.m. ...	93	20
5	5	3	15	9	16	9	47	28	From 9.53 p.m. ...	86	13
6	1	11	19	36	1	16	28	54	From 10.45 p.m. ...	78	39
7	2	3	6	24	6	9	17	68	From 11.38 p.m. ...	68	24
8	5	2	5	16	18	7	18	57	From 12.34 p.m. ...	57	14
9	17	16	5	8	37	35	11	17	From 1.30 a.m. ...	46	37
10	6	7	2	6	29	33	10	29	From 2.30 a.m. ...	34	39
11	5	2	4	7	28	11	22	39	From 3.28 a.m. ...	24	22
12	9	3	2	5	47	16	10	26	From 4.26 a.m. ...	15	25
13	14	4	0	3	67	19	0	4	From 5.22 a.m. ...	7	17
14	6	5	6	3	30	25	30	15	From 6.16 a.m. ...	3	19
15	1	0	0	1	50	0	0	50	None	0	14
16	4	4	1	0	44	44	11	0	None	0	15
17	4	0	4	1	44	0	44	11	Until 8.14 p.m. ...	3	10
19	1	1	0	0	50	50	0	0	Until 9.49 p.m. ...	14	3
20	1	1	1	2	20	20	20	40	Until 10.35 p.m. ...	23	10
21	4	1	3	0	50	12	38	0	Until 11.21 p.m. ...	30	4
22	2	0	1	1	50	0	25	25	Until 12.07 a.m. ...	39	6
25	0	12	8	9	0	41	28	31	Until 2.30 a.m. ...	67	13
26	10	12	4	8	29	35	12	24	Until 3.19 a.m. ...	76	11
27	4	2	2	12	20	10	10	60	Until 4.07 a.m. ...	84	36
28	3	6	12	7	11	21	43	25	Until 4.55 a.m. ...	90	39
Mar.											
3	1	16	4	5	4	62	15	19	From 6.55 p.m. ...	100	39
4	10	6	8	2	39	23	31	7	From 7.47 p.m. ...	99	19
5	4	3	7	15	14	10	24	52	From 8.40 p.m. ...	95	16
6	0	1	4	7	0	8	33	59	From 9.35 p.m. ...	89	10
7	3	1	4	17	12	4	16	68	From 10.30 p.m. ...	81	47
8	2	5	5	8	10	25	25	40	From 11.26 p.m. ...	71	7
9	4	2	2	22	14	6	6	74	From 12.24 a.m. ...	60	12
10	0	0	0	3	0	0	0	100	From 1.23 a.m. ...	49	8
Total	143	177	173	282	18	23	22	37			
Total	775										713
Weighted percentage, in one lunar circle					27·5	21·8	20·9	29·7			

TABLE IV.

Relation between time of entry of *A. funestus* and time of moonlight.

Moonlight	Dates	Catch of *A. funestus*				
		Total number caught	Percentage caught			
			8 p.m.	10 p.m.	mid-night	7 a.m.
No moon	13/ii, 14/ii, 15/ii, 16/ii, 17/ii, 19/ii.	63	48%	22%	17%	13%
New moon, setting 10.30 p.m.-12.30 a.m.	20/ii, 21/ii, 22/ii	17	41%	12%	28%	18%
New moon, setting 2.30 a.m.-4.30 a.m.	25/ii, 26/ii, 27/ii	83	17%	31%	17%	35%
Full moon	30/i, 31/i, 28/ii, 3/iii, 4/iii.	116	18%	26%	26%	30%
Waning moon, rising 8.0 p.m.-9.30 p.m.	3/ii, 4/ii, 5/iii	150	8%	33%	27%	33%
Waning moon, rising 9.30 p.m.-11.30 p.m.	5/ii, 6/ii, 6/iii, 7/iii, 8/iii.	149	7%	14%	32%	47%
Waning moon, rising 11.30 p.m.-1.30 a.m.	7/ii, 8/ii, 9/ii, 9/iii, 10/iii.	142	20%	16%	13%	51%
Waning moon, rising 1.30 a.m.-4.30 a.m.	10/ii, 11/ii, 12/ii	58	34%	21%	14%	31%

Table IV records the percentage of mosquitos caught at 8 p.m., 10 p.m., midnight, and 7 a.m. at different phases of the moon, and these results are expressed in histogram form in fig. 2. Although the number of mosquitos involved is small, the results show a consistent trend, and the only appreciable exception is in the second phase of the moon, when the 10 p.m. and midnight catches are below and above expectation, respectively; in this period only 17 mosquitos were caught, so the results are understandably less accurate. In the 10 p.m., midnight and 7 a.m. catches the maximum percentage was obtained when the moon arose during the period in question, and this was followed by a sharp drop in the period immediately following when the moon rose just after the catch had occurred, and when the minimum percentage catches were usually obtained. Thus the 10 p.m. catch dropped from 33 to 14 per cent., the midnight catch from 32 to 13 per cent., and the 7 a.m. catch from 51 to 13 per cent. The maximum percentage catches obtained at 10 p.m., midnight and 7 a.m. were approximately 50, 100 and 400 per cent. greater, respectively, than the proportion caught during these periods on moonless nights.

The 8 p.m. catch was maximal during the moonless period, which also embraced the very early moon, and it gradually declined and was minimal in the period after full moon, when the moon rose after this catch was completed. In this instance the variation is greatest, as the percentage caught on moonless nights was six times the percentage caught on nights after full moon. The very large numbers caught in the 8 p.m. catch on moonless nights indicate that mosquito flighting is largely inhibited during moonless periods, and that on moonless nights the mosquitos, which have been waiting to flight on the previous night, flight at dusk when twilight provides conditions similar to those of moonlight.

(*b*) *Correlation between time of entry of ♀ A. funestus and time of moonlight.*

The correlation between the time of flighting and the time of moonlight is complex, because the catch at any period of any night can only be expressed as a percentage of the total catch for the whole night. If at any time the presence of a moon increases the number of Anopheline entrants, then the percentage entry at that period will be increased, but the percentage entry at all other periods of the same night will in consequence be decreased. The relative extent of the increase and decrease is variable, and the factors which determine it are considered in Appendix II, an analysis of the effect of moonlight on a hypothetical population. In practice the relative extent of these two values can be determined empirically, and therefore inexactly, by the use of multiple correlation coefficients, since the more correct values yield the higher coefficients. But such a method must always underestimate the real extent of the relation.

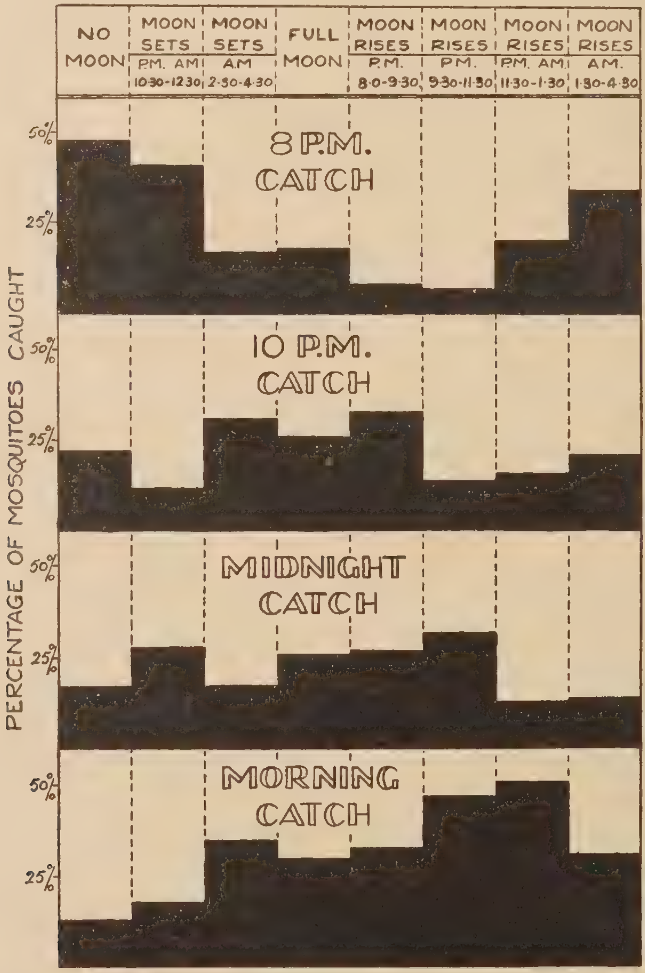

FIG 2.—Relation between time of entry of female *A. funestus* and time of flighting.

Table V records the correlation coefficients obtained when the percentage of Anophelines entering at each period is compared with the duration of moonlight during the night, both within and without this period. A strictly quantitative estimate of moonlight would take into account the phase and the declination of the moon as well as the duration of moonlight. But when two series of correlation coefficients were prepared, the former showing the correlation between mosquito catches and the number of minutes of moonlight, and the latter showing the correlation between the catches and the product of the number of minutes of moonlight and the phase of the moon, the former were invariably higher than the latter. Hence it was concluded that mosquito behaviour was sensitive to the presence or absence of a moon, rather than in a strictly quantitative manner. This of course does not imply that there was no strictly quantitative response—probably the response was quantitative at very low concentrations of moonlight and soon reached, and thereafter maintained, a maximum. This would also explain the very high correlations obtained, since under these circumstances the presence or absence of cloud would be less likely to upset the correlation—however dense the cloud may be, a considerable quantity of moonlight always penetrates it.

TABLE V.

Correlation coefficients, moonlight and % *A. funestus*.

		Correlation coefficients between Anopheline catch and			
		(1)	(2)	(3)	(4)
		Duration of moonlight at catching time.	Moonlight at catching time minus moonlight before and after catching time.	Moonlight at catching time minus one-quarter of the moonlight before catching time.	Moonlight at catching time minus three-quarters of the moonlight before catching time.
Catching Time.	6·30—8 p.m.	0·014 ± 0·174	**0·783 ± 0·067**		
	8·0—10 p.m.	0·260 ± 0·162		**0·261 ± 0·162**	
	10·0—midnight	0·470 ± 0·138		**0·580 ± 0·117**	
	midnight—7 a.m.	0·460 ± 0·140	0·534 ± 0·126	0·500 ± 0·133	**0·563 ± 0·121**

For this reason the phase and declination of the moon were ignored, and the duration of moonlight, in minutes, used in all the calculations now given.

The 7-8 p.m. catch shows no correlation between the percentage entering and the duration of moonlight within this period, but there is a high negative correlation, −0·762±0·073, between the percentage then entering and the duration of moonlight after 8 p.m. There is a still higher positive correlation, 0·783±0·068, when the percentage entering before 8 p.m. is compared with the duration of moonlight before 8 p.m., less the duration after this time. Hence I conclude that the percentage entering between 7-8 p.m. is mainly determined indirectly, by the effect of moonlight on later catches, but the direct effect of moonlight within the period plays a small part.

The 8-10 p.m. catch yielded the maximum correlation coefficient, 0·261±0·162, when the catch was compared with the number of minutes of moonlight during this period, less one-quarter of the number of minutes of moonlight before it. The

10 p.m.-midnight catch yielded the maximum correlation coefficient, $0 \cdot 580 \pm 0 \cdot 117$, when a similar criterion of comparison was used. When the effect of moonlight after these periods was also considered the correlation was less—this was presumably due to over-correction because the effect of moonlight later in the night is smaller, for a reason which will be considered later.

The midnight-7 a.m. catch showed maximum correlation, $0 \cdot 563 \pm 0 \cdot 121$, when compared with the number of minutes of moonlight during this period, less three-quarters of the number of minutes of moonlight before midnight.

Hence the correlation at each period was significantly related to the duration of moonlight. The early catch showed a very close relationship, but this was decreased in the later catches partly owing to the increased difficulty in making the necessary empirical adjustments, and partly owing to the smaller size of the 8 p.m.-midnight catches, which decreased the chances of obtaining a representative sample of the population.

(c) *Correlation between time of entry of ♀ A. melas and time of moonlight.*

These experiments were made at Aberdeen. Four natives were employed, in rotation. They retired at approximately 6 p.m. and slept in separate huts. Each night one of the natives was wakened at 8 p.m. and sent into another empty hut, and this process was repeated at 10 p.m. At both 8 p.m. and 10 p.m. I sprayed the vacated hut and collected the mosquitos by torchlight, and mosquitos were collected from all the occupied huts next morning, under supervision.

It should be remembered that 8 p.m. at Aberdeen is equivalent to 9 p.m. at Krabonekrom, since sunset occurred 1 hour earlier at Aberdeen.

TABLE VI.

Entry of ♀ *A. melas*.

Date, 1941	Number of ♀ *A. melas* caught			Ratio. Catch at 10 p.m. : catch at 7 a.m.	Time of moonlight	No. of *A. melas* in undisturbed control (average of 2 controls)
	8 p.m.	10 p.m.	7 a.m.			
Aug.						
27	0	21	6	78 : 22	Until 8.40 p.m. ...	5
29	0	1	3	25 : 75	Until 10.20 p.m. ...	12
31	0	7	1	87 : 13	Until 12.20 a.m. ...	27
Sept.						
1	0	3	3	50 : 50	Until 1.10 a.m. ...	11
2	0	0	12	0 : 100	Until 2.10 a.m. ...	7
3	2	4	1	80 : 20	Until 3.00 a.m. ...	9
4	0	1	8	11 : 88	Until 4.00 a.m. ...	18
5	3	9	14	39 : 61	Until 4.50 a.m. ...	25
6	6	0	10	0 : 100	Until 5.40 a.m. ...	35
7	2	8	4	67 : 33	Until 6.40 a.m. ...	18
8	6	33	79	30 : 70	All night	41·5
9	0	12	15	44 : 56	From 7.30 p.m. ...	14·5
12	4	4	38	10 ; 90	From 9.40 p.m. ...	24
13	4	5	12	30 : 70	From 10.20 p.m. ...	32
15	0	2	15	12 : 88	From midnight ...	85
16	2	5	10	33 : 67	From 12.50 a.m. ...	48
17	8	7	18	28 : 72	From 1.40 a.m. ...	45·5
18	12	16	23	41 : 59	From 2.30 a.m. ...	54
19	0	5	21	19 : 81	From 3.20 a.m. ...	61·5
20	0	10	11	48 : 52–7	From 4·20 a.m. ...	31·5
21	4	22	29	43 : 57	From 5·20 a.m. ...	29·5
Total	45	175	333			
Total		553				634

Table VI records both the number and the percentage of *A. melas* obtained in each collection on each of 21 days between 27th August and 21st September, 1941, and it also records, from data compiled from *The Nautical Almanac*, 1941, the time of moonrise and moonset in this locality at these times. The results now being discussed form only a scientific by-product to the practical conclusions which these experiments were originally designed to obtain, and because of military duties it was seldom possible for me to supervise this experiment before 8 p.m.; for this reason the irregular arrival of the natives made the 8 p.m. catch unreliable, and no conclusions have been drawn from it. Hence when calculating the percentage catch and the correlation coefficients only the mosquitos entering between 8 p.m. and 7 a.m. were considered. The correlations obtained were lower than those at Krabonekrom, probably mainly because of this restriction and partly because of the smaller number of collections.

A correlation coefficient of 0·421 ± 0·184 was obtained when the percentage of *A. melas* entering between 8 p.m. and 10 p.m. was compared with the number of minutes of moonlight during this period, less one-half the number of minutes of moonlight after this period. The percentage entering after 10 p.m. yielded a correlation coefficient 0·386 ± 0·191 when compared with the number of minutes of moonlight after 10 p.m. less the number between 8 p.m. and 10 p.m.

These correlation coefficients are barely significant, since their chance of occurrence in a random sample is more than 1 in 20 ($P = 0·05$ for a correlation coefficient of 0·433; Fisher, 1941). Yet in view of the highly significant correlations found in the case of *A. funestus*, it is not likely that the correlation is fortuitous, and had a more complete sample been obtained, I think that a highly significant correlation would have been found in the case of *A. melas* also.

(*d*) *Conclusions concerning the influence of moonlight on Anopheline flighting.*

These experiments have proved a high degree of correlation between the time of moonlight and the time of entry of ♀ *A. funestus* and indicated a similar but possibly less complete relationship in the case of ♀ *A. melas*. It may be expected that ♀ *A. gambiae* exhibit similar behaviour, and there is a possibility that the relationship is of more general application among night-flying insects.

It cannot be proved that this relationship is a direct one and not due to correlation between moonlight and some third factor which in its turn controls mosquito behaviour, but the size of the correlation indicates the presence of a direct relationship, and moonlight is known to exert important effects on the behaviour of other insects.

Oviposition experiments have shown that females of *A. minimus*, a close relative of *A. funestus*, can distinguish between different light intensities as small as one-fourth of starlight (Thomson, 1940), so mosquitos certainly possess the capacity to distinguish between moonless and moonlit nights. Analysis of catches of many species of insects in light-traps shows that catches are usually much lower on moonlit nights (Williams, 1936 & 1940; Robertson, 1939), but light-traps only indicate how many insects have been attracted to the trap, and it is reasonable to expect that a much higher proportion of the flighting population will be attracted to a light-trap on moonless nights. In this connection it is interesting to note that the conclusions drawn from light-trap experiments concerning the relation between insect flighting and moonlight are exactly opposite to the conclusions now presented concerning the behaviour of *A. funestus* and *A. melas* in relation to moonlight.

In view of the high correlation between time of moonlight and time of flighting it might be expected that there would be a correlation between the duration of moonlight and the number of Anophelines caught each day. The correlation coefficient expressing this relationship, for *A. funestus* at Krabonekrom, has the value of 0·400 ± 0·146, while that for *A. melas* at Aberdeen is 0·082 ± 0·222. The latter value is obviously not significant, and examination of the catches at Krabonekrom leads me to conclude that the former value is due to a coincidence and not to any genuine relationship. The *A. funestus* population there fluctuated very considerably, and had peak populations at intervals of about 14 days (Ribbands, 1944 *a*) and it happened that in the period of the experiments one of these peaks occurred near each period of full moon, and the peak intervening between these two peaks was not very pronounced (as it had been a month previously)—these circumstances are sufficient to account for the size of the correlation coefficient, and it is not necessary to assume any direct relation between the duration of moonlight and the total number of Anopheline entrants on any day.

Moreover, it is biologically improbable that for the several successive moonless days a large proportion of the mosquito population would be deterred from feeding by the absence of moonlight. How then does moonlight exert its effects? The large size of the 8 p.m. catches during moonless periods provides a clue to the answer; at these times not merely is the percentage of Anophelines caught before 8 p.m. much greater, but the actual numbers are also greater. Hence complete darkness is apparently not favourable for flighting, but either twilight or moonlight are suitable, and mosquitos ready to feed usually wait until these suitable conditions occur.

Morning twilight is not so favourable for feeding as evening twilight, probably because the instinct to find shelter dominates the feeding instinct at this time, and therefore on moonless nights mosquitos which become ready to feed after evening twilight usually do not feed until twilight the next evening. As the moon waxes, the number of mosquitos decreases, until at full moon, when conditions for flighting are favourable throughout the night, very few remain unfed at dawn and ready to feed at commencement of evening twilight. Therefore at full moon the 8 p.m. catch is reduced. As the moon wanes, mosquitos are deterred from entry early in the evening (unless they have been ready to feed at twilight), and they flight in maximum numbers when the moon rises.

The catch at moonrise includes not merely the mosquitos then becoming ready to feed, but also many of those which have been waiting to feed during the previous moonless period, and this explains why it is greater than the catch which would have occurred at this time of the night if the moon had been out the whole night. It also explains why when calculating the correlation coefficients of 10 p.m. and midnight catches it was necessary to weight the quantity of moonlight in these statistics, because the presence of each hour of moonlight before the period in question greatly reduced the percentage catch, but the presence of each hour of moonlight after it had little effect.

The Anopheline behaviour now described is highly correlated with moonlight and twilight, but this never delays feeding by as much as 24 hours, and therefore should have no major effects upon the life-cycle.

It would be very interesting to have more details of Anopheline behaviour in areas such as that at Kisumu, where Haddow's results indicate that evening twilight is not a suitable time for Anopheline flighting.

The average Time of Entry.

(*a*) *Average time of entry of ♀ A. funestus at Krabonekrom.*

The high correlation between time of moonlight and time of flighting shows that it is useless to compile records of average time of flighting and entry unless either there are so many readings that the effects of the lunar cycle cancel out, or weighted averages of percentage catches are used so that each period of the lunar cycle has the correct proportional effect. The latter method has been necessary when dealing with the data collected in the present series of experiments.

Thus weighted, the average rate of entry of ♀ *A. funestus* throughout one complete lunar cycle at Krabonekrom was 27 per cent. before 8 p.m., 22 per cent. between 8 p.m. and 10 p.m., 21 per cent. between 10 p.m. and midnight and 30 per cent. after midnight. (The less accurate unweighted averages were 24, 19, 20 and 37 per cent. respectively.)

(*b*) *Average time of entry of ♀ A. gambiae at Krabonekrom.*

Only 55 ♀ *A. gambiae* were collected on 25 different days during the experiment, and this total is quite insufficient to enable accurate deductions to be drawn directly. It was, however, possible to compare the percentage of *A. gambiae* entering at each period of each night with the percentage of *A. funestus* entering at the same period of the same night: using this method it was found that there were 6, 20, 27 and 47 per cent. of *A. gambiae* caught at 8 p.m., 10 p.m., midnight and 6 a.m. respectively, and 21, 23, 18 and 37 per cent. of *A. funestus* at the same periods of these nights. The possible effect of the lunar cycle was counterbalanced by weighting proportionally the catches of both species until the percentages of *A. funestus* corresponded with the weighted percentages given above; the average rate of entry of *A. gambiae* was then approximately 10 per cent. before 8 p.m., 20 per cent. between 8 p.m. and 10 p.m., 30 per cent. between 10 p.m. and midnight and 40 per cent. after midnight.

The total catch of ♀ *A. gambiae* was so small that deductions drawn from it are not statistically significant. However, these figures are given, in spite of this handicap, because they indicate a possible difference between the behaviour of *A. gambiae* and *A. funestus,* and this difference is similar to that which can be deduced from other results, which will be mentioned later.

(*c*) *Average time of entry of ♀ A. melas at Aberdeen.*

In view of the likelihood that the 8 p.m. catch is smaller than it would have been if proper supervision had been possible between 6 p.m. and 8 p.m. detailed conclusions cannot be drawn, but calculations showed that *at least* 45 per cent. of the average catch, weighted in accordance with the lunar cycle, entered before 10 p.m. (=11 p.m. Krabonekrom time).

(*d*) *Comparison of time of entry in West and East Africa.*

Demonstration of the close relationship between duration of moonlight and time of entry renders valueless most previous observations of the time of flighting of the species concerned, because they were made over a short period and without reference to moonlight. Haddow's work, however, consists of 53 observations made every seventh day for a year, and this series is large enough to merit the expectation that the effects of moonlight will be largely cancelled.

The histograms in fig. 3 facilitate comparison between the average times of flighting at Kisumu, Kenya, as recorded by him, and the average times now recorded from West Africa. There is a marked difference between these records, for both female *A. funestus* and female *A. gambiae*, for whereas at Krabonekrom 70 per cent. of *A. funestus* and 60 per cent. of *A. gambiae* entered within 5½ hours of sunset (*i.e.*, before midnight) at Kisumu only 45 per cent. of *A. funestus* and 40 per cent. of *A. gambiae* entered within this period; hence the average time of flighting was later at Kisumu.

The possibility that the discrepancies between these results are due to differences in technique are discussed in Appendix I. But they may be the result of some other difference, such as climate.

Whereas the experiments at Krabonekrom were made during the dry season, in fine weather, Haddow reports bad evening weather at Kisumu. He says " Most of the rainfall occurs in the late afternoon or early evening. High winds are common at this time of day, and electric disturbances with thunder and lightning take place almost every evening ". But Kisumu rainfall is small (less than 40 ins.) and such factors seem too inconstant to account for such a difference.

Another climatic factor is different in the two localities—humidity. Records supplied to me by the Meteorological Officer, R.A.F., at Takoradi, five miles from Krabonekrom, show that during the 33 days on which the *A. funestus* experiment was conducted the temperature range at 6 p.m. was 81-85°F., with an average of 82·8°F., and the relative humidity at this hour ranged from 73-91 per cent., with an average value of 84·2 per cent., and with only four days less than 79 per cent. At 4 a.m. the temperature range was 71-78°F., average 75·2°F., and relative humidity ranged from 91-99 per cent., with an average value of 96·5 per cent. Haddow gives humidity records for November and December, 1940, only. He shows that on wet days relative humidity reached 80 per cent. by 6 p.m., and stayed around this value throughout the night, but on dry days relative humidity averaged 55 per cent. at 6 p.m., 63 at 8 p.m., 66 at 10 p.m., 72 at midnight, and 78 between 2 a.m. and 6 a.m.—a rapid increase in humidity with a maximum after midnight. Now these months were above the yearly average for Kisumu rainfall, but in spite of this their mean relative humidity figures indicate that on about half of the days the relative humidity varied as on the dry days. Any retardation of flighting at humidities under 70 per cent. would thus account for the difference between the two sets of results—but no such effect has been recorded anywhere, so far as I know.

At Aberdeen, where *A. melas* flighted early, the temperature range at 7 p.m. was 72·3-85·0°F., with an average of 74·2°F., and the relative humidity at this hour varied from 65-95 per cent., with an average value of 80·4 per cent. and with only one evening below 73 per cent. At 7 a.m. the temperature range was 73·0-77·0°F., and the relative humidity ranged from 89-97 per cent. with an average value of 94 per cent.

(*e*) *Comparison between the behaviour of ♀ A. gambiae and that of ♀ A. funestus.*

When the average times of flighting of *A. gambiae* and *A. funestus* at Kisumu are compared (fig. 3), it can be seen that while Haddow's comment, " the period of high entry (of *A. funestus*) begins 3 hours later than does that of *A. gambiae* ", is strictly true, it is an incomplete statement of the difference. For in both species the average rate of entry for the ninth, tenth and eleventh hours of darkness was 9·5 per cent. per hour, and the greatest difference was that in the second, third and fourth hours the average rate for *A. funestus* was 6·8 per cent., but for *A. gambiae* it was only 5·3 per cent. per hour; this difference was compensated between the fifth and eighth hours when the *A. funestus* rate was 7·1 per cent. and the *A. gambiae* rate rose to 8·75 per cent. per hour. Thus the essential difference between the two species at Kisumu was that *A. funestus* tended to flight *earlier* than *A. gambiae* and this difference was compensated for in the middle of the night, when *A. gambiae* were more active than *A. funestus*.

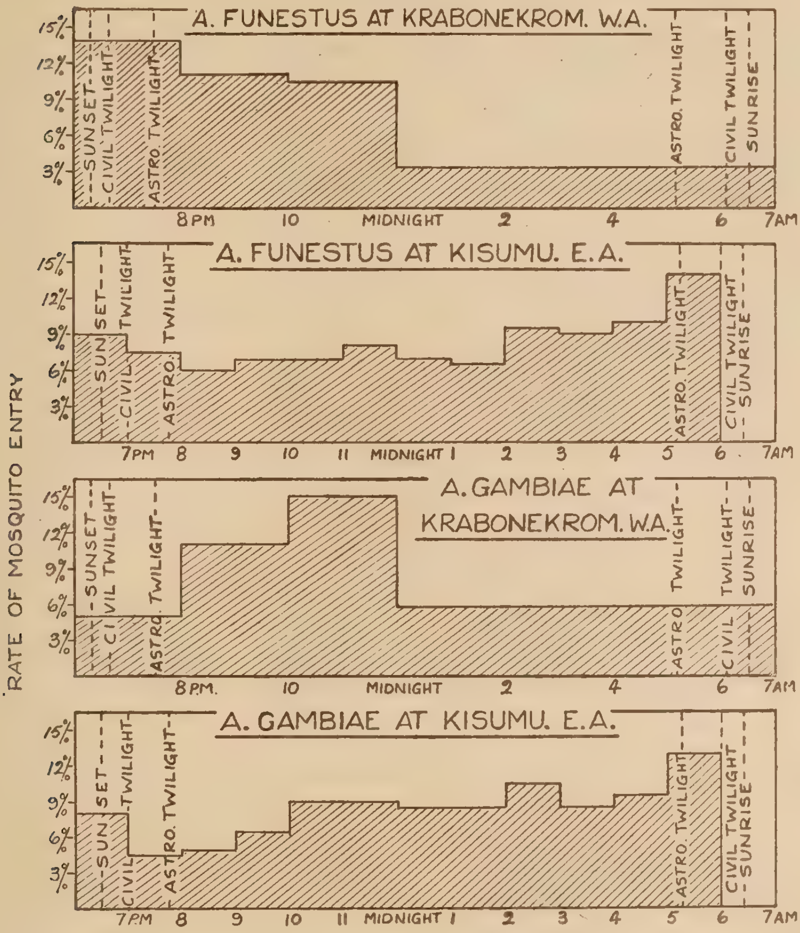

Fig. 3.—Comparison of hourly rate of mosquito entry at Krabonekrom and Kisumu. Kisumu records compiled from Haddow (1942).

This difference was emphasised at Krabonekrom, where conditions for early flighting were more favourable. There the entry peak of ♀ *A. funestus* (18 per cent. per hour) occurred during the first 1½ hours after sunset, and 49 per cent. had entered by 10 p.m., but the entry peak of ♀ *A. gambiae* (15 per cent. per hour) occurred between 10 p.m. and midnight, and only 30 per cent. had entered by 10 p.m.

Haddow's results indicate that at Kisumu ♀ *A. funestus* were more active than ♀ *A. gambiae* at dawn; this would be a likely corollary of their behaviour at dusk and indicates that they are more crepuscular in their habits than *A. gambiae*.

The Time of Feeding.

The proportion of fed mosquitos in the catches.

Anophelines do not always feed as soon as they enter the hut that contains their host. This fact is clearly demonstrated by the results from Krabonekrom, where the natives were carefully supervised and were always found asleep until they were disturbed by the experimenter, and it is confirmed by the similar results from Aberdeen.

TABLE VII.

Proportion of fed mosquitos.

Time caught	KRABONEKROM														ABERDEEN (8 p.m. = 9 p.m. Krabonekrom time)						
	A. funestus							*A. gambiae*							*A. melas*						
	Number				Percentage			Number				Percentage			Number				Percentage		
	Total	Gorged	Partly fed	Unfed	Gorged	Partly fed	Unfed	Total	Gorged	Partly fed	Unfed	Gorged	Partly fed	Unfed	Total	Gorged	Partly fed	Unfed	Gorged	Partly fed	Unfed
8 p.m. ...	139	47	11	81	34%	8%	58%	3	0	0	3	0%	0%	100%	28	12	0	16	43%	0%	57%
10 p.m. ...	177	138	11	28	78%	6%	16%	11	8	2	1	73%	18%	9%	104	72	7	25	69%	7%	24%
Midnight ...	167	147	8	12	88%	5%	7%	14	13	0	1	93%	0%	7%	29	24	2	3	83%	7%	10%
6 a.m. ...	270	255	8	7	94%	3%	3%	26	25	0	1	96%	0%	4%	231	229	1	1	99%	1%	

Table VII shows the variation in the proportion of fed mosquitos caught at different times. All the fed mosquitos caught during the evening were filled with fresh blood, and there was no evidence that either partly-fed or gravid mosquitos ever entered the huts. The small percentage of partly-fed females all contained fresh blood, and were probably interrupted in their feed—most of them by the entry of the experimenter to awake and remove the natives. The smallness of this percentage indicates that the Anopheline in nature normally becomes fully gorged at one sitting, just as it does in the laboratory.

The large percentage of unfed females in the 8 p.m. catches shows that early entrants usually rest after entry before they feed. Since so large a proportion rest inside the hut before feeding, it is likely that others similarly rest for a period on the outside walls of the hut to which they have been attracted. In such circumstances the average time at which flighting finishes would be earlier than the average time of entry into the huts.

The average time of feeding.

The high percentage of unfed females in the early evening catches indicates that records of time of entry (*e.g.*, Haddow, 1942) are not strictly comparable with those of time of biting (*e.g.*, Kerr, 1933), and in assessing malaria risks the time of biting is the more important factor.

The average time of biting of *A. funestus* at Krabonekrom was calculated, results being based on the supposition that all mosquitos caught unfed would have fed during the following 2-hourly period. The biting rate was 5·8 per cent. per hour before 8 p.m., 17·2 per hour between 8 p.m. and 10 p.m., 11·4 per hour between 10 p.m. and midnight, and 3·4 per hour after midnight. The numbers of *A. gambiae* were too small to make similar calculations worthwhile.

Anopheline Habits in relation to Malaria Prevention.

(*a*) *Destruction of adult Anophelines in native dwellings.*

The three most important malaria carriers in Tropical Africa are *A. gambiae*, *A. funestus* and *A. melas*. Females of all three species nearly always remained until after dawn in the native huts in which they had fed, and most of them remained there throughout the following day. This fact justified the policy of malaria reduction by regular daytime treatment of all native dwellings with pyrethrum spray. This method is now likely to be superseded by the use of DDT as a residual anti-adult insecticide, and it is useful to know that the strong house-haunting habits of these mosquitos provide a maximum chance that they will acquire a lethal dose of DDT.

(*b*) *Destruction of Anophelines in European quarters.*

Anophelines in European dwellings can only be usefully killed *before* they have fed. The large proportion (*circa* 60 per cent.) of unfed females in the 8 p.m. catches from huts in which the human inhabitants were asleep, and the likelihood of an even higher proportion if they had been awake and alert, indicates that spraying of European dwellings between 1 and 2 hours after sunset should have useful effects. If such sprays were proved to have a partial short-term repellent effect, this would increase still further the justification for such a measure.

The fact that mosquitos usually rest after entry and before feeding explains how large freshly-applied doses of residual DDT on walls are able to protect the room occupants against biting, because they incapacitate the mosquito during its short preliminary resting period.

(*c*) *Personal precautions.*

The results now presented emphasise the importance of taking adequate personal precautions during *the whole period* between, and including, dusk and dawn. Whereas these results emphasise the greater importance of dusk catches, in European quarters dawn may be equally important since mosquitos unable to feed may linger about ready to feed when disturbed. I have witnessed biting *A. gambiae* under such conditions at 11 a.m., but in well-ventilated quarters bites more than half an hour after dawn are probably rare.

The maximum malaria risk occurs during the hours of moonlight, and at twilight on moonless nights.

(*d*) *Anopheline surveys.*

The consistent house-haunting behaviour of the most important malaria carriers justifies the use of regular catches of mosquitos from selected houses as a guide for, and an index to the success of, control measures.

The conclusion that no daytime exit occurs from really suitable huts means that the results of surveys of adult mosquitos in such suitable huts are comparable irrespective of the period of the day at which they were made.

Summary.

1. 97 per cent. of the ♀ *A. gambiae, A. funestus* and *A. melas* remained until after dawn in the huts in which they had fed.

2. ♀ *A. melas* seldom left suitable huts in the daytime.

3. There was a high positive correlation between the time at which ♀ *A. funestus* entered huts and the time of moonlight. The maximum correlation coefficient was between the size of the catch at 8 p.m. and the duration of moonlight after this period, and its value was $-0{\cdot}783 \pm 0{\cdot}068$.

4. During moonless periods, the flighting of ♀ *A. funestus* was partially inhibited, and when the moon came out, the waiting mosquitos entered the huts in greatest numbers. The average proportion caught when the moon rose during catching periods ending 10 p.m., midnight and 7 a.m. was approximately 50 per cent., 100 per cent. and 400 per cent. greater, respectively, than the proportion caught during these periods on moonless nights. On moonless nights many mosquitos waited until twilight of the following evening before entering the huts, and in consequence the average proportion caught in the period ending 8 p.m. was six times greater on moonless nights than on the nights after full moon.

5. The records for ♀ *A. melas* are less complete, and the correlation coefficient for the relation between time of entry and time of moonlight has the value $0{\cdot}421 \pm 0{\cdot}184$, a result which is barely significant. In view of the highly significant correlations found in the case of *A. funestus* it is unlikely that this correlation is fortuitous.

6. The average rate of entry of ♀ *A. funestus* throughout one complete lunar cycle at Krabonekrom, Gold Coast, was 27 per cent. before 8 p.m., 22 between 8 p.m. and 10 p.m., 21 between 10 p.m. and midnight and 30 after midnight. The similar rates for *A. gambiae* (based on very few records), were 10, 20, 30 and 40 per cent. respectively. Comparable rates for *A. melas* in Sierra Leone are not available, but at least 45 per cent. entered before 10 p.m. (=11 p.m. Gold Coast time).

7. The essential difference between the behaviour of ♀ *A. funestus* and that of *A. gambiae* is that the former flight earlier than the latter. *A. funestus* also seem to be more active at dawn, so that they are more crepuscular in their habits than *A. gambiae.*

8. 58 per cent. of the Anophelines caught at 8 p.m. were unfed. This indicates that early entrants usually rest after entry and before feeding, and average time of biting is later than average time of entry. Gravid or half-gravid mosquitos and those containing partly-digested blood, did not enter the huts; there was evidence that Anophelines usually became fully gorged at one feed. Of the Anophelines caught in huts after dawn 95 per cent, were fully fed.

References.

Blacklock, D. B. & Wilson, C. (1941). Ann. trop. Med. Parasit., **35,** pp. 37-42.

Causey, O. R., Deane, L. M. & Deane, M. P. (1943). Amer. J. trop. Med., **23,** pp. 73-94.

Fisher, R. A. (1941). Statistical Methods for Research Workers. 8th Edn.—London, Oliver and Boyd.

Gordon, R. M., Hicks, E. P., Davey, T. H. & Watson, M. (1932). Ann. trop. Med. Parasit., **26,** pp. 273-345.

Haddow, A. J. (1942). Bull. ent. Res., **33,** pp. 91-142.

Kerr, J. A. (1933). Bull. ent. Res., **24,** pp. 493-510.

Ribbands, C. R. (1944*a*). Bull. ent. Res., **35,** pp. 271-295.

——. (1944*b*). Ann. trop. Med. Parasit., **38,** pp. 85-86, 87-99.

8 381 Robertson, A. G. (1939). J. Anim. Ecol., **8,** pp. 300-322.

Ross, G. A. P. (1936). Quart. Bull. Hlth Org. L.O.N., **5,** pp. 110-113.

3 68 Thompson, R. C. M. (1940). J. Malar. Inst. India, **3,** pp. 165-294.

204 Williams, C. B. (1936). Phil. Trans. roy. Soc., (B) **226,** pp. 357-389.

52 ——. (1940). Trans. R. ent. Soc. Lond., **90,** pp. 227-306.

Appendix I.

The relative Efficiency of Hand and Spray Catching of Mosquitos.

On 60 days between 18th February and 8th May, 1941, I made careful hand catches in the huts at Aberdeen, and these were immediately followed by spray catches; 494 Anophelines were obtained, 353 of which were caught by hand and 141 by the subsequent spray catch. Thus 28 per cent. of the Anophelines present were overlooked in the hand-catching, although these huts were specially constructed for ease in mosquito-catching—being of small size, with a maximum ceiling height of 7 feet, and lined with straw-coloured matting on which the mosquitos could easily be seen. The only furniture was a small bed raised 2 feet from the ground at one side of the room, and this bed was also, of course, examined. At the time of hand-catching, the doors were opened and there was abundant natural illumination, supplemented in corners by torchlight.

The chief disadvantage of hand-catching for scientific purposes was not the failure to capture 28 per cent. of the Anophelines but the considerable variation in the percentage of the total which were captured. On 13 occasions 10 or more mosquitos were obtained from one room at one time. On 4 of these occasions 90 per cent. or more of the catch were obtained by hand, but on 3 occasions only 50 per cent. or less were obtained by hand-catching. This wide variation in efficiency, under very favourable conditions, indicates that hand-catching results cannot be used for the study of day-to-day fluctuations with good prospects of exactitude.

Hand-catching results obtained by Haddow (1942), who has criticised spray-catching, can be compared with the spray-catching results now presented. His hand-catches show that very large numbers of both *A. funestus* and *A. gambiae* were caught at dusk—and that a very high proportion of these mosquitos had already fed. A possible explanation is that these were uncaught entrants of the previous night, which had shifted to more visible resting places during the day.

If only a proportion of the mosquitos present are caught, then during night catches the total number present will accumulate as the night progresses; if the same proportion of the total continue to be caught on each occasion, the effect will be to make the average time of entry appear later than it actually is. This might partially account for the differences between Haddow's results and those now presented.

Any human inefficiency is most likely to occur in relation to unfed and male mosquitos, because these are most difficult to see. Analysis of Haddow's records (in his Table XVI) shows that the number of male *A. funestus* collected in night catches averaged 2·7 per night, while day catches yielded 13·7 per morning; on the expectation that the sex ratios were the same in both cases the night catches, which finished at dawn, produced only 22 per cent. of the expected numbers of males. With efficient catching, this result could only be explained if 78 per cent. of the males entered their huts *after* dawn. Comparison of Haddow's catches with the spray catches now recorded shows differences in the ratios of unfed to fed females. Whereas the spray catches of *A. funestus* show very high proportions of unfed females in the early evening (Table VII, ratio of unfed to fed is 1·4 to 1), Haddow obtained a much lower proportion (0·25 to 1).

In all these four cases the discrepancies are considerably greater in the case of *A. funestus* than in the case of *A. gambiae,* and the latter is a larger mosquito.

These comments are criticisms of the method of hand-catching, and not of the work of Haddow in particular, and they are prompted because other results, which will be published later, indicate similar but even more marked discrepancies between spray and hand-catching results in the case of *A. minimus*.

Appendix II.

Effect of Moonlight on a hypothetical Population.

Since no absolute values are known, the mosquito catch at any period of the night can only be expressed as a percentage of the total catch for the whole night; but if during one hour of that night the presence of a moon increases the number of entrants then the percentage entry at that period will be increased, but the percentage entry at all other periods of the same night will in consequence be decreased. There is no constant relation between the relative extent of the increase and the decrease, as the following calculations show:—

(*a*) Suppose that the basic rate of entry is 27, 22, 21 and 30 per cent. respectively during the four successive periods of the night (the average rate of entry of *A. funestus* at Krabonekrom) and that 10 per cent. of the entire night catch will be obtained as an extra catch in any period in which occurs one hour of moonlight. Should this hour of moonlight occur within the first period, the catch then would be increased to 34·3 per cent. of the total, but should it occur outside this period the catch would be reduced to 24·3 per cent. of the total, *i.e.*, moonlight would increase the catch by 27 per cent. if within the period, or decrease it by 10 per cent. if outside it—a ratio of 2·7:1. The similar ratios for the other periods of the night would be 3·6:1 and 3·8:1 and 2·3:1 respectively.

(*b*) The average rate of entry of *A. funestus* on moonless nights at Krabonekrom was 48, 23, 14 and 15 per cent. respectively over the four periods. If one hour of moonlight produced an extra catch of 10 per cent. of the entire night catch during any period in which it occurred, then the ratio between the increase in the percentage catch which would occur if it fell within the first period and the decrease to this catch if it fell without this period is 1·05:1. The ratios for the other periods are 3·5:1 and 6·1:1 and 5·6:1 respectively.

(*c*) Suppose the basic rate of entry was again 48, 23, 14 and 15 per cent. respectively, but that one-half the total catch occurred during one hour of moonlight and the rest were distributed in these percentages. The ratio between the increase in the percentage which would occur if the moonlight occurred within the first period and the decrease in it if the moonlight fell without this period is 1·09:1. The similar ratios for the other periods are 5·3:1 and 8·1:1 and 7·7:1 respectively.

These examples show that there is no constant relation between the effect of moonlight within and without a period on the percentage catch. Examples (*a*) and (*b*) show that the relative sizes of the effects are mainly determined by the size of the basic percentage catch at that period, but comparison of (*b*) and (*c*) demonstrates that the ratio varies to a lesser degree with the size of the effect due to moonlight.

These variations cannot be exactly estimated, and hence maximum correlations can only be determined empirically, and therefore inexactly, by the use of multiple correlation coefficients. Such a method must always underestimate the real extent of the relationship.

THE INFLUENCE OF CERTAIN BIOLOGICAL FACTORS ON THE RESISTANCE OF BED-BUGS (*CIMEX LECTULARIUS*, L.) TO DDT.

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Introduction.

The work described below forms part of an investigation to determine the residual toxicity of DDT when applied to the surface of materials commonly used in the construction of buildings. The bed-bug (*Cimex lectularius*, L.), because of its wide distribution and habit of infesting surfaces, either exposed or hidden, is an eminently suitable subject for such an investigation. In order to compare the residual toxicity of different surfaces after treatment with DDT, it was considered an essential preliminary step to ascertain whether or not the biological condition of the insect influenced its resistance to the insecticide. The present investigation was, therefore, undertaken to establish any possible variations in resistance which could be correlated with one or more of the following biological factors:—

1. starvation for different periods;
2. sex;
3. stage in the life-history;
4. temperature.

Material and Technique.

Except where it is stated otherwise, the bugs used throughout the present work were obtained from a laboratory culture[1] maintained at 25° C. and fed on rabbit blood at weekly intervals.

The sample of DDT used was the pure para para compound free of isomers, with melting point 109° C. Varying concentrations of DDT in odourless distillate[2] were sprayed directly on to bugs by means of a tower, originally devised by Potter (1941), to give different deposits of DDT per square centimetre of surface[3]. During spraying and for twenty-four hours after, the bugs were kept on the same filter paper. Where this method of direct spraying was unsuitable, bugs were exposed for two hours on filter papers which had been impregnated with a solution of DDT in a volatile solvent to give a constant average deposit of solute per square centimetre of surface. After either twenty-four hours or two hours, according to the method of treatment, the insects were transferred to clean recovery tubes and kept at the appropriate temperature for a period of six days, at the end of which mortality counts were made.

Variations in Resistance.

(*a*) *Effects of starvation and sex.*

The possibility that resistance to DDT during starvation might vary according to sex, or, in the case of the female, according to virginity or gravidity, made it convenient to investigate the influence of these factors in conjunction with each other. Groups of adults, each group consisting of either males, gravid or virgin females, were accordingly segregated after the third blood meal of their adult life and starved for either 1, 2, 3, 5, 7, 10 or 20 days. At the end of the starvation period the bugs were sprayed with either 1 c.c. of a 0·4 per cent. solution of DDT in odourless distillate to give a deposit of 0·00144 mg. of DDT per sq. cm., or, in the case of the control series, with the same volume of odourless distillate alone. The mortalities obtained among all three classes of adults, sprayed with odourless distillate alone, after starvation for intervals varying from 1-10 days was 0 per cent. After starvation for 20 days, among males similarly sprayed mortality was 5 per cent.; among gravid females, 6 per cent.; and among virgin females, 0 per cent. It is clear, therefore, that the toxicity of odourless distillate at the different periods of starvation was negligible. The percentage mortalities obtained among the three classes of adults sprayed with DDT solution after the specified periods of starvation are given in Table I.

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[1] The bugs comprising this culture were originally collected from the London Area.

[2] A refined light oil, slightly above paraffin cut; S.G. ·779; B.P. 200° — 260°C; flash point (closed), 71°C; viscosity, Redwood I, 32 sec. at 20°C.

[3] 1 c.c. of odourless distillate sprayed in a Potter tower gave a deposit of 0·36 mg. per sq. cm.

Table I.

Percentage mortalities among bugs (males, gravid and virgin females) sprayed, at different intervals of starvation, with DDT solution to give a DDT deposit of 0·00144 mg./cm.^{2}

Days starved	♂♂	Gravid ♀♀	Virgin ♀♀
1	44% (39)	36% (36)	30% (30)
2	18% (38)	30% (36)	28% (30)
3	10% (40)	27% (40)	7% (22)
5	7% (54)	69% (41)	13% (30)
7	27% (44)	84% (44)	50% (32)
10	35% (69)	70% (45)	83% (30)
20	67% (40)	85% (41)	84% (30)

(In this and in all subsequent tables, the numbers of bugs from among which each per cent. mortality was obtained is given in brackets.)

These figures show that (i) between the limits of the starvation period selected, the male bug is most resistant to DDT three to five days after feeding, and the females, both gravid and virgin, about three days after; (ii) during the period of 10-20 days starvation, the male is more resistant than the female, either gravid or virgin; (iii) the resistance of virgin females during the first seven days of starvation is consistently higher than that of gravid females during the same period.

The resistance of the males and of both types of females 24 hours after feeding was lower than after starvation for five and three days, respectively. It was thought that this low initial resistance might be explained by the insect dragging its engorged abdomen along the surface of the filter paper on which it had been placed during the spraying, thereby exposing a greater surface of contact with the DDT deposit than would be exposed by a bug with a less distended abdomen after starvation for three or five days. To test this, the ventral abdominal surface of a number of males, gravid and virgin females was coated with a thin film of wax 24 hours after they were fed and immediately before they were sprayed with 1 c.c. of a 0·4 per cent. solution of DDT. The wax film was left in position during spraying and for 24 hours after, to prevent contact with the contaminated filter paper, and was removed when the insects were transferred to clean recovery tubes. Of the males so treated, 45 per cent. died, of the gravid females, 40 per cent., and of the virgin females 28 per cent. As seen from Table I, these figures do not differ appreciably from the percentage mortalities obtained among non-waxed males, gravid and virgin females similarly sprayed 24 hours after feeding. It is apparent, therefore, that the cuticle of the abdominal surface is not the main site of penetration of DDT into the insect body. The reasons for the relatively high mortalities 24 hours after a blood meal are probably physiological and as such are beyond the scope of this paper.

(*b*) *Stages of life-history.*

Batches of eggs, all laid during the same 48 hours by females kept under identical conditions, were sprayed within 24 hours of laying with 2 c.c. of a 5 per cent. solution of DDT in odourless distillate, giving a deposit of 0·036 mg. DDT per sq. cm. Eggs used as controls were sprayed with 2 c.c. of odourless distillate alone. In both series the number of eggs which had hatched by the twelfth day after laying was recorded. Of those eggs sprayed with DDT solution, 60 per cent. hatched but only 2 per cent. of the resultant nymphs survived. Only 41 per cent. of the eggs sprayed with odourless distillate hatched, but 20 per cent. of the nymphs survived.

Thus even when used at a relatively high concentration, DDT is not ovicidal, but the percentage of surviving nymphs from treated eggs is very small, owing, no doubt, to the nymph coming into contact, when it first emerges, with the insecticide deposited on the egg case.

In order to compare their resistance to DDT, groups of nymphs at each stage and newly emerged adults of both sexes were sprayed with 1 c.c. of either a 0·2 or 0·4 per cent. solution of DDT in odourless distillate to give deposits of either 0·00072 or 0·00144 mg. DDT per sq. cm., or, for control purposes, with 1 c.c. of odourless distillate alone. Individuals of all stages, including adults, were allowed a single blood meal before being sprayed. Since it was difficult to determine with certainty the sex of the immediately pre-adult individuals, any variation in resistance which might be correlated with sex was investigated in young adults only. The results, summarised in Table II, show that bugs in the pre-adult stages of their life-history are susceptible to poisoning by both the solvent and solute used, this susceptibility diminishing during successive instars. Young adults appear to show no variation in their resistance which can be correlated with sex.

TABLE II.

Percentage mortalities among bugs sprayed with DDT at different stages of their life-history.

Stage	Odourless distillate	0·00072 mg.DDT/cm	0·00144 mg.DDT/cm^2	
I	100% (30)	100% (30)	—	
II	95% (27)	100% (26)	—	
III	62% (26)	100% (26)	—	
IV	35% (35)	96% (30)	—	
V	6% (30)	52% (29)	65% (30)	
♂	0% (28)	10% (30)	40% (40)	young adults
♀	0% (30)	10% (30)	48% (35)	

In spite of the susceptibility of the pre-adult stages to odourless distillate, the percentages given in columns 2 and 3 of Table II suggest that resistance to DDT *alone* also increases as the life-history progresses. This was confirmed by exposing bugs at the different instars for a period of two hours on filter paper impregnated with DDT in acetone to give an average deposit of 0·1 mg. of solute per sq. cm.[1] The percentage mortalities obtained by this method are given in Table III.

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[1] The minimum volume of acetone necessary to ensure that the filter paper was evenly wetted was ascertained. This volume, containing the requisite amount of DDT, was then distributed as quickly as possible over the surface of the filter paper, which was allowed to dry before testing.

TABLE III.

Percentage mortalities among bugs exposed at different stages in their life-history to a dry film of DDT (0·1 mg./cm²).

Stage	I	II	III	IV	V	Adults	
						♂	♀
% mortalities ...	100 (30)	100 (29)	75 (36)	30(30)	20 (25)	0 (31)	0 (30)

(*c*) *Temperature.*

Adult bugs, selected at random independent of their sex but fed on the same dates, were kept for at least two months at temperatures of 23, 25 and 30° C. They were then sprayed with 1 c.c. of either a 0·25 or 0·4 per cent. solution of DDT to give either 0·009 mg. or 0·00144 mg. DDT per sq. cm. The insects were then stored for six days, at the temperature at which they had been originally kept, before mortality counts were made. The percentage mortalities obtained by these tests are given in Table IV.

TABLE IV.

Percentage mortalities among bugs, kept for at least 2 months at different temperatures, when sprayed with DDT solution.

Deposit of DDT (mgs./cm².)	23° C.	25° C.	30° C.
0·00144	0% (42)	7% (42)	12% (42)
0·009	15% (48)	19% (48)	41% (48)

It is seen that the percentage of kills among bugs maintained at 30° C. are consistently greater than among those kept at 23 and 25° C., these latter showing no appreciable difference in their mortalities.

General Conclusions.

Adult bugs are more resistant to DDT than nymphs; among nymphs, resistance increases at each successive instar.

There is no difference in resistance among recently fed *young* males and females. The resistance of adult males after ten to twenty days starvation is greater than that of females, either gravid or virgin, starved for a similar period. During the first seven days of starvation virgin females are more resistant than gravid ones.

The resistance of males and gravid and virgin females is lower twenty-four hours after feeding than after starvation for five and three days respectively.

Bugs kept at 30° C. are less resistant than those kept at 23 and 25° C.

DDT is not ovicidal but the percentage of nymphs surviving from eggs sprayed with DDT is small.

I wish to express my thanks to Professor P. A. Buxton, F.R.S., for his kind and helpful criticism of this work; to the Medical Research Council, by whom it was financed; and to Dr. J. R. Busvine, Ministry of Health, for his advice on technical procedure.

References.

POTTER, C. (1941). Ann. appl. Biol., **28**, pp. 142-169.

NOTE SUR L'EMPLOI DE LA PASTEQUE, *CITRULLUS VULGARIS*, SCHRAD. (CUCURBITACEAE) DANS LA PREPARATION DES APPATS EMPOISONNES.

By A. Mallamaire.

Durant l'année 1943, au cours de la campagne de lutte contre le criquet pèlerin (*Schistocerca gregaria*, Forsk.), il a été fait un large emploi des fruits de la pastèque (*Citrullus vulgaris*, Schrad.) dans les régions sahéliennes de l'Afrique Occidentale Française, des côtes de la Mauritanie à la rive occidentale du lac Tchad.

Les difficultés nées de la guerre recente, difficultés de fourniture, de transport et d'emballage, n'ayant pas permis d'obtenir du son de blé, base excipiente de loin la meilleure pour la préparation des appâts empoisonnés à base de fluosilicate de soude (car très appétée par les criquets et économisant l'emploi de mélasse ou de miel), il a été fait appel à un certain nombre de succédanés, tels que: balle et son de mil (*Sorghum* spp. et *Pennisetum americanum*), balle et son de riz, paille de brousse hachée, herbe fraîche et notamment "bourgou" frais (*Echinochloa stagnina, E. pyramidalis*), paille d'arachides, tourteau pulvérisé d'arachides, coques broyées d'arachides, cadavres frais de criquets, excréments d'animaux (crottin de cheval et d'âne, bouse de vache, fumier de bovins et ovins) et fruits de pastèque cultivée ou sauvage.

La pastèque africaine ou melon d'eau (*Citrullus vulgaris*, Schrad.) donne des fruits de forme et de dimension variables allant de la taille d'un potiron à celle d'une orange; la chair en est rouge ou blanche plus ou moins sucrée et les graines blanches, rougeâtres ou noires. C'est un légume-fruit très cultivé en Afrique, aussi bien dans les régions soudanaise et sahélienne que dans le Sahara et sur ses bordures nord et sud; il en existe de nombreuses variétés appréciées par les différentes races de ces régions.

Il existe également des formes sauvages, les unes à gros fruits et à pulpe douceâtre et comestible (var. *silvestris*, Schwf.), les autres, à petits fruits et à pulpe amère, non comestible (var. *colocynthoides*, Schwf.).

La culture de cette plante est extrêmement facile; il suffit de mettre quelques graines en terre au début de la saison des pluies, en juin-juillet, pour récolter d'août à novembre de grandes quantités de fruits; en Mauritanie et au Sénégal la pastèque est couramment cultivée pour l'obtention des graines oléagineuses comestibles (béref). La plante est très rustique et s'accomode de tous les terrains sablonneux; elle resiste à une certaine sécheresse et donne une fructification abondante même les années de pluies déficitaires.

La pulpe sucrée et très aqueuse de la pastèque constitue à elle seule une base excipiente suffisante qui est très appétée par les criquets et qui permet d'éviter d'addition de mélasse, miel ou saccharine dont d'emploi, comme attractif, est presque obligatoire en A.O.F. quand le son de blé fait défaut.

Il suffit de couper finement les fruits et de les saupoudrer de fluosilicate de soude, à raison de 4 k. de produit toxique pour 100 k. environ de pulpe; l'appât ainsi préparé doit être répandu dans la journée et au plus tard le lendemain matin car il est fermentescible.

Le pouvoir couvrant de l'appât est assez faible, mais cela est compensé par le grand pouvoir attractif qu'exerce la pulpe de pastèque sur les criquets. Dans les régions sahéliennes presque dépourvues de végétation, où l'on peut trouver de grandes quantités de pastèques, soit cultivées, soit sauvages, qu'il suffit de ramasser et de découper au couteau, les fruits de cette plante constituent un appoint précieux pour la lutte antiacridienne.

En 1943, dans la Colonie du Niger, l'appât préparé avec de la pulpe, a été répandu directement sur les taches de criquets, à l'aide de camions Ford G.T.B. avec trois hommes à l'arrière pour distribuer le produit; cette méthode a été jugée efficace, très rapide et a permis de réaliser une grosse économie de main-d'oeuvre, ce qui est très intéressant dans les régions semi-désertiques.

Bibliographie.

CHEVALIER, A. (1932). Les productions végétales du Sahara et de ses confins nord et sud.—Rev. Bot. appl., **12,** pp. 669-924.

DALZIEL, J. M. (1937). The useful plants of west Tropical Africa, pp. 54-55. London.

MALLAMAIRE, A. (1944). Compte-rendu de la mission d'organisation de la lutte contre le criquet pèlerin (*Schistocerca gregaria,* Forsk.) en Afrique Occidentale Française en 1943.—Macina (Soudan) (inédit).

NOTES ON THE SUBGENUS *COQUILLETTIDIA* DYAR (DIPTERA, CULICIDAE).

By J. D. Gillett.

(By permission of the Director of Medical Services, Uganda.)

Introduction.

The widespread distribution and blood-thirsty nature of some of the species of the subgenus *Coquillettidia* of the genus *Taeniorhynchus* have earned for them a place amongst the most unpleasant of the blood-sucking insects in the whole continent of Africa. Although none of these species has yet been actually incriminated in the field as a vector of disease, there is experimental evidence of their capacity to act in this way. Daubney and Hudson (1933) have conducted experiments which suggest that *T. versicolor, T. fuscopennatus* and *T. microannulatus* are possibly connected with the transmission of Rift Valley fever, as they found that the virus can be conveyed to laboratory animals by injection of the infected extract of these mosquitos. Apart from their possible rôle in the transmission of disease, the aggressive and persistent nature of some of the species cannot but have a deleterious effect on anyone unfortunate enough to be within range of their attacks. *T. fuscopennatus,* largely a homophilic feeder with a very widespread distribution, including such widely separated territories as Abyssinia, Tanganyika, Natal and Angola, is perhaps the worst in this respect. It is so persistent in its attentions, and at times appears in such large numbers, that it constitutes a real nuisance to the community. It makes its presence felt in rural and urban districts alike, feeding mainly by night, and in Uganda has been the cause for bitter complaint to the Medical Department for many years.

Owing to the highly specialised habits of the early stages of *Taeniorhynchus,* the larvae and pupae of most of the Ethiopian species have escaped detection until very recently. It has been known that the larvae and pupae must inhabit water associated with aquatic or semi-aquatic vegetation, and further, that although the output of adults increases substantially during rainy seasons, newly emerged adults of some species appear in considerable numbers throughout the year. It would seem, therefore, that their breeding places must be restricted to permanent or semi-permanent collections of water supporting aquatic plants. In spite of these clues most attempts to find the early stages have failed. Of the 15 species* of the subgenus known to occur in the Ethiopian region (excluding the Malagasy subregion), the early stages of *T. aurites* and *T. microannulatus* were the only species that had been described by the beginning of 1944 (Hopkins, 1936 and Edwards, 1941). Recently, however, two more have been added to the list; Wanson (1944) has described the egg, larva and pupa of *T. metallicus,* and Gillett (1945) has described the larva and pupa of *T. maculipennis.*

During the year 1944 a serious attempt to find the early stages of at least some of the other species that occur in Uganda has resulted in the capture and successful rearing of *T. versicolor, T. pseudoconopas, T. fuscopennatus* and a new species, which it is proposed to call *atroapicalis* (see p. 436). Altogether, during this work, 190 fourth-instar *Coquillettidia* larvae have been taken and isolated, from which the following have been reared to the adult stage: 11 *T. metallicus,* 8 *versicolor,* 4 *pseudoconopas,* 24 *maculipennis,* 4 *fuscopennatus,* 34 *aurites,* 4 *microannulatus* and 15 *atroapicalis.* With the exception of that of *T. metallicus,* the larvae of all these species very closely resemble one another, but with experience most of them can be fairly readily separated.

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* Only 14 species are listed by Edwards (1941), but recently the writer has found a new species, bringing the total to 15.

Technique.

On account of the unusual habits of *Taeniorhynchus* larvae, ordinary dipping methods in "grassy" swamps and other suspect places usually fail to yield any *Taeniorhynchus*, although larvae of the subgenus *Mansonioides* may sometimes be taken in this way. Therefore other means of capture had to be devised, and the technique to be described was not arrived at without much trial and error. It was known that adults of most of the species listed above were plentiful in Entebbe, *T. metallicus, pseudoconopas, maculipennis, fuscopennatus* and *aurites* all having been taken in the act of feeding on man. Whenever adults of one or more of the species with unknown larvae are taken, a search is begun to find the nearest water of a permanent or semi-permanent nature, however small, containing aquatic vegetation.

When such water is found in the vicinity of the captured adults, handfuls of the aquatic vegetation are uprooted and a large white enamel basin thrust in underneath the roots. Some of the larvae are disturbed by the sudden uprooting of their anchorages and swim sluggishly about the water feeling for a new root or stem on which to fasten themselves anew. They are thus trapped in the basin, which is removed and allowed to stand for 30 seconds or so in order to allow the mud to settle. The water is then decanted off very slowly. The moment this operation is begun all larvae other than those of *Taeniorhynchus* rise rapidly to the surface and are easily dispensed with. Not until the basin is all but empty, and there is a depth of less than 1 cm. of water covering the mud-coated bottom, do the *Taeniorhynchus* larvae show themselves. They are seen as pale coloured, fat, sluggish larvae moving in the slow manner characteristic of larvae of this genus. Many of the species can be recognised at once, even with the naked eye, by their colour and shape.

This method has proved so successful that it has produced within two months the larvae of all the species known to occur in their adult form in Entebbe, with the addition of the new species mentioned above. During September, 1944, the writer had occasion to visit Kabale in south-western Uganda where it was known that *T. versicolor* occurs. Within two days of arrival the technique was applied and *Coquillettidia* larvae were taken, which on rearing proved to be those of *T. versicolor.*

Various aquatic plants and grasses have been tried for rearing purposes without much success, the difficulty being that in the conditions provided, and probably in the field also, larvae and pupae of the subgenus are very slow in developing, the pupal stage being from six to eleven days (depending on temperature). Most plants tried die before the adult is ready to emerge, and the pupa dies with it. Wanson (1944) describes an ingenious method of rearing *T. metallicus* by inserting a U-shaped piece of special thick paper into the water container, the larvae and pupae attaching themselves to the paper. The writer, however, has had complete success with the plant, *Commelina africana.* Short, rooted sprigs of this plant will live in a narrow test-tube of water for two months or more, during which time both roots and shoots grow rapidly. Eight different species of *Coquillettidia* have been reared from larva to adult in narrow test-tubes of water containing this plant.

On capture the living larvae are identified (when of a known species), and isolated in narrow test-tubes of water containing the plant. They very soon hook on and provided they have an ample food supply develop normally. Should for some reason the plant become damaged or die, the larva may be shaken off by quickly raising the plant until the larva is above the surface of the water, and then submerging it again. It may be necessary to repeat this performance once or twice before the larva drops off. When the larva is clear of the roots the plant may be removed and a new one substituted, to which the larva will very soon anchor itself. When the larva pupates, the whole plant together with the attached pupa may be lifted out gently and placed into another tube of water. This will not harm the pupa if it is done quickly, and has the advantage of leaving the larval skin in the old tube, from which it may be removed without risk of touching the new pupa with a pipette or needle.

Unlike the larva, should the pupa be removed from its anchorage it will never hook on again, but will rise to the surface and behave like the pupae of other genera. If left undisturbed at the surface in most cases the adult will emerge normally. Pupae left fastened to the roots of a plant will themselves rise to the surface usually a few hours before eclosion of the adult. In some cases this will happen as much as a day or two before the time.

Morphology.

As pointed out above, with the notable exception of *T. metallicus,* all the known African larvae and pupae of *Coquillettidia* show a remarkable similarity to one another. It is, however, possible to determine most of the species, even though in several instances the differentiating characters are very slight. In fact, it is possible to separate the living larvae of all the known species by means of a hand lens, but this needs considerable practice. *T. aurites* and *T. microannulatus,* which can only be separated in their pupal stages and then only with difficulty, are two exceptions.

The few characters that can be used for determination of the species are, in the larva, the antenna, tuft B on the eighth abdominal segment, and (in one case) the comb; in the pupa the paddles are the only structures that have been found useful. In the descriptions of species that follow it is unnecessary to mention all the characters that are uniform throughout the subgenus, and only the important structures that can be used for identification have been included. It is as well, therefore, to include a description of a typical *Coquillettidia* larva and pupa before describing each species separately, but before doing this one explanation is necessary.

In the larvae the position of the antennal tuft is the most useful character that can be relied upon in identification, but owing to the presence of the extraordinary, long and flexible flagellar segment of the antenna the customary method of describing the position of the tuft as a fraction indicating the length of the portion of the shaft of the antenna proximal to the tuft divided by the total length of the antenna is not suitable. The position of the tuft can very suitably be expressed, however, by the same method if the flagellar segment be excluded. In other words the part of the shaft that can be used for expressing this fraction is the portion of the antenna proximal to the subterminal setae. In his description of *T. maculipennis,* Gillett (1945) refers to this portion of the antenna as the pedicellus, and it is proposed to do the same here. It should be noted that the portion of the pedicellus proximal to the tuft is about the same length in all the known species of the subgenus, and it is only the portion of the pedicellus distal to the tuft which varies according to the species (fig. 1).

The following description applies to all the Ethiopian species of *Coquillettidia* so far discovered, with the exception of *T. metallicus*:

LARVA.

Medium sized, pale coloured larvae readily separated from those of all other Ethiopian genera by their highly modified siphons (which are specialised for piercing aquatic plants) and by their short head setae. From the subgenus *Mansonioides* they may be separated by the enormously long flagellar segment of their antennae.

Length from 5 to 9 mm.; *colour* pale greyish white to bright green or blue; head brownish yellow; valves and basal ring of siphon black.

Head broader than long. Antenna weakly spiculate up to the subterminal setae; tuft of about 30 plumose hairs on the inner aspect placed between ½ and ⅘ according to species; flagellar segment at least as long as the pedicellus; longer subterminal seta between ½ and ⅞ the length of the flagellar segment. Clypeal spines long and slender. Setae A and B short tufts of 8-12 plumose branches, C smaller with 5-6 branches, *d* shorter than A and B, with 5-7 branches.

Abdomen.—Comb, a row of 6-10 sharp pointed spines, with a basal fringe; very weakly sclerotised. Tuft B of eighth segment long, plumose and single or double according to species. Ring and valves of siphon black; subventral tuft with about 5-6 branches. Saddle of anal segment complete, and covered with spicules, which are most prominent dorso-distally; lateral seta moderately large, with about 12 branches; upper caudal seta with about 10 branches, lower with about 8. Ventral brush consisting of 4 pairs of about 10 simple branches; in addition there are from 5-7 small unpaired tufts proximal to the barred area, extending along the ventral surface of the saddle. The "gills" are intentionally omitted from this description as they are unreliable as a means of identification, their size depending largely on the salinity of the water (Wigglesworth, 1933).

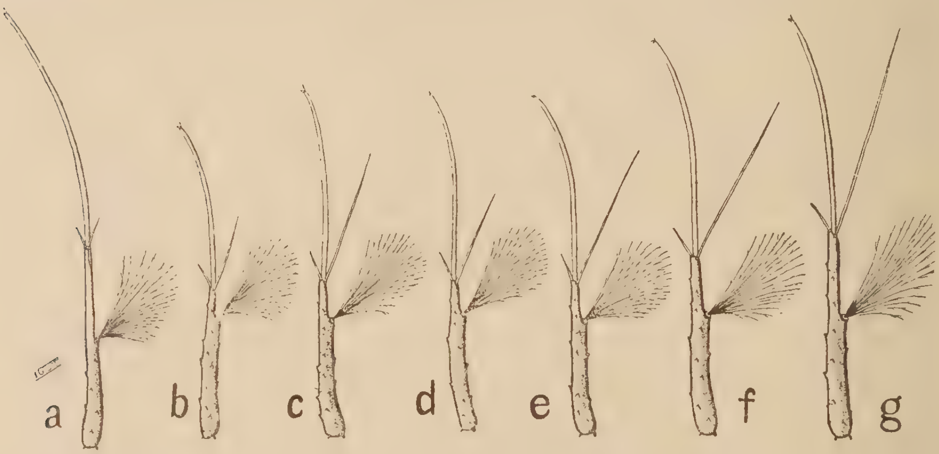

FIG. 1.—Larval antennae of *Taeniorhynchus* (*Coquillettidia*) spp.
(a) *metallicus.* (b) *maculipennis.* (c) *fuscopennatus.* (d) *pseudoconopas.*
(e) *atroapicalis.* (f) *versicolor.* (g) *aurites* and *microannulatus.*

PUPA.

Readily distinguished from those of other genera by the highly modified respiratory trumpet (which is specially adapted for piercing aquatic plants) and by the replacement of the float hair on the first abdominal tergite by a single seta. The minute abdominal setae make them easily separable from pupae of *Mansonioides.*

Paddles from 3-4½ times as long as their maximum width; notched at tip, the points so formed being equal or unequal according to species. Paddle-hair wanting.

Abdomen covered with minute points, except for a smooth area in the middle of each tergite; posterior margin of each tergite conspicuously serrated.

Respiratory trumpet mainly cylindrical, but generally with a slight bulbous widening immediately distal to the tracheoid portion of the meatus, followed by a sudden tapering off before the base of the pinna (fig. 2*b*).

Taxonomy.

Key to the known fourth-stage Larvae of Coquillettidia.

(The flagellar segment is excluded when reference is made to the position of the antennal tuft.)

1. Tuft B of eighth abdominal segment double 2
   Tuft B of eighth abdominal segment single 4

2. Subterminal setae of antenna nearly equal in length, and both very short; saddle almost smooth; no tufts proximal to barred area ... ... *metallicus*
   Subterminal setae of antenna unequal in length, the longer at least about $\frac{1}{2}$ length of flagellar segment of antenna ... 3

3. Antennal tuft at about $\frac{4}{5}$; longer subterminal seta of antenna not longer than $\frac{1}{2}$ length of flagellar segment ... ... *maculipennis*
   Antennal tuft at about $\frac{3}{4}$; longer subterminal seta of antenna from $\frac{2}{3}$-$\frac{3}{4}$ length of flagellar segment ... ... *fuscopennatus*

4. Antennal tuft from $\frac{3}{4}$-$\frac{4}{5}$ 5
   Antennal tuft from $\frac{4}{7}$-$\frac{2}{3}$ 6

5. Antennal tuft at about $\frac{4}{5}$; longer subterminal seta of antenna about $\frac{1}{2}$ length of flagellar segment ... ... *pseudoconopas*
   Antennal tuft at about $\frac{3}{4}$; longer subterminal seta of antenna about $\frac{2}{3}$ length of flagellar segment ... ... *atroapicalis*

6. Antennal tuft at about $\frac{2}{3}$; longer subterminal seta of antenna about $\frac{2}{3}$ length of flagellar segment ... ... *versicolor*
   Antennal tuft at about $\frac{4}{7}$; longer subterminal seta of antenna from $\frac{3}{4}$-$\frac{7}{8}$ length of flagellar segment ... ... *aurites* and *microannulatus*

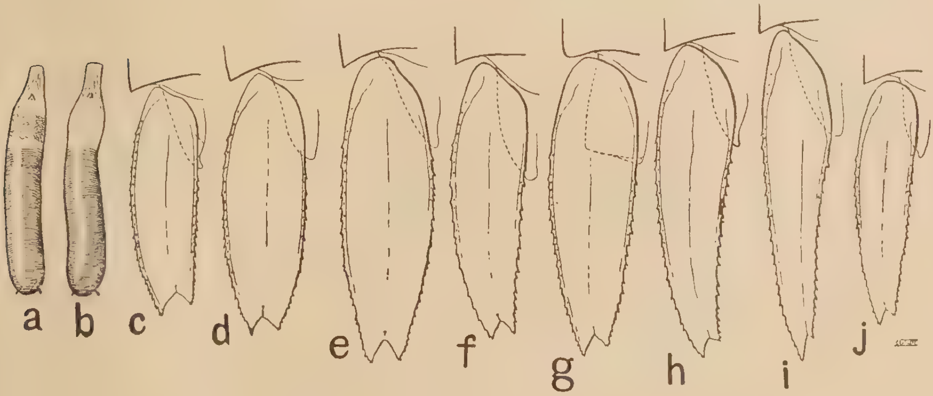

FIG. 2.—Pupal details of *Taeniorhynchus* (*Coquillettidia*) spp.

Respiratory trumpets (pinnae missing) of (a) *metallicus*; (b) *atroapicalis*.
Paddles of (c) *metallicus*; (d) *pseudoconopas*; (e) *aurites*; (*f*) *microannulatus*; (*g*) *versicolor*; (h) *fuscopennatus*; (i) *atroapicalis*; (j) *maculipennis*.

The pupal differences are so minute that without practice it will not be possible to make use of the key given below. It is not possible to use it with absolute accuracy and it is merely intended as a guide, although the writer has used it with success.

Key to the known Pupae of Coquillettidia.

1.	Dark band on the reticulate portion of the meatus	*metallicus*
	No such dark band on the reticulate portion of the meatus ...	2
2.	Points of paddle equal, or nearly so	3
	Outer point of paddle at least twice length of inner	5
3.	Small pupa; paddle with outer point sharper and darker than inner, length only 3 times maximum width, margins convex	*pseudoconopas*
	Large pupa; length of paddle about 3½ times maximum width	4
4.	Dark coloured pupa	*aurites*
	Pale yellowish colour	*microannulatus*
5.	Large pupa	6
	Small pupa	7
6.	Outer point of paddle twice length of inner	*versicolor*
	Outer point of paddle about three times length of inner; inner margin of paddle concave	*fuscopennatus*
7.	Outer point of paddle about twice length of inner	*maculipennis*
	Outer point of paddle from 4-6 times length of inner	*atroapicalis*

Taeniorhynchus (Coquillettidia) metallicus, Theobald.

LARVA (figs. 1*a*, 3).—Described by Wanson (1944) from material collected in the Congo. The description below is from 11 pelts, and 6 whole larvae from Entebbe, Uganda, July, 1944. The Uganda material agrees in every way with that from the Congo.

Small bright green (occasionally bright blue) larva, readily separated from other known Ethiopian *Coquillettidia* larvae by its colour, the short subterminal seta and the absence of tufts proximal to the barred area.

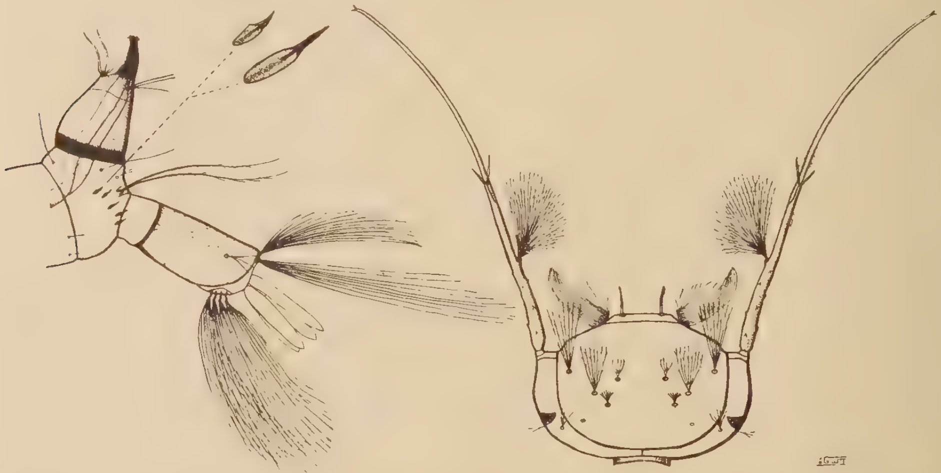

FIG. 3.—*Taeniorhynchus* (*Coquillettidia*) *metallicus*, Theo. Terminal segments and head of larva.

Length about 5 mm.; *colour* bright green, or bright blue.

Head.—Antenna weakly spiculate below tuft; tuft at about ½ (excluding flagellar segment); flagellar segment very long and slender, nearly one and a half times length of pedicellus; distal portion of pedicellus semi-flexible; subterminal setae both short and nearly equal in length, the inner being slightly longer. Seta A moderately long with 8-12 plumose branches, B with 8-10 plumose branches, C with 9-10 branches and *d* with 3-6 branches.

Abdomen.—Comb a row of 4-6 very dark simple spines without any basal fringe. Tuft B of eighth segment long, plumose and double, arising from a well developed basal tubercle. Subventral tuft with 3 branches. Saddle, although appearing smooth in balsam mounts, actually covered with very minute spicules; lateral seta small with 4 branches; upper caudal seta with about 15 branches, lower with 10; no tufts proximal to the barred area.

PUPA (figs. *2a*, *2c*).—Described by Wanson (1944) and now redescribed from 11 pelts from Entebbe, Uganda. Readily distinguished from the other known pupae of the subgenus by the presence of a dark band on the reticulate portion of the trumpet (fig. *2a*).

Paddles 2½-3½ times as long as their greatest width; points widely separated, the angle between them being nearly 90°; the outer point slightly wider and longer than the inner.

Abdomen covered with minute points, including the whole of the tergites; these points and the denticles on the posterior margin of the tergites being larger than in other known African species of *Coquillettidia*.

Respiratory trumpet without any bulbous widening at distal end of meatus, and with a distinct dark transverse band round the wide part of the reticulate portion. Pinna missing in the Entebbe material.

Breeding places.—Found with larvae of *T. aurites, africanus* and *uniformis* in shallow " grassy " swamps, and small collections of water through which aquatic vegetation is growing.

Notes.—When pupating this larva has the extraordinary habit of breaking off its antennae from its head, and separating its head capsule from the rest of its cuticle, thus leaving the pelt in four pieces; *i.e.*, (i) and (ii) the two antennae, (iii) the head and (iv) the thorax and abdomen. If the pelts or even whole larvae are mounted in balsam the long slender flagellar segment of the antenna curls up, very often into a tight corkscrew spiral. Perfectly satisfactory mounts are obtained, however, if they are mounted directly into Polyvinyl alcohol, for which the writer is indebted to Mr. G. G. Robinson, of Northern Rhodesia.

Oviposition has been observed to take place during the night—the egg raft consisting of about 12 rows of 20 eggs each.

Taeniorhynchus (Coquillettidia) versicolor, Edwards.

LARVA (fig. *1f*) hitherto undescribed. 8 pelts from Kabale, Uganda, September, 1944. Large blue-white larva, only likely to be confused with those of *T. aurites* and *microannulatus,* from which it may be separated by the position of the antennal tuft, and the length of the longer subterminal seta of the antenna.

Length 7-8 mm.; *colour* whitish to bluish white.

Head.—Antenna weakly spiculate up to subterminal setae; tuft at ⅔ (excluding flagellar segment); longer subterminal seta usually ⅔ (nearly ¾ in one specimen) length of flagellar segment.

Abdomen.—Tuft B on eighth segment long, single and very weakly plumose, with only the merest trace of a basal tubercle.

PUPA (fig. *2g*) hitherto undescribed. 8 pelts from Kabale, Uganda, Readily distinguished from other pupae of the subgenus by the shape of the paddles, large size and, in the male, the shape of abdominal segment X.

Paddles 3½-4 times as long as their greatest width; wide near base, and tapering gradually to the tip; outer point about twice length of inner.

Abdomen.—Segment X square-shaped in the male.

ADULT.—Edwards (1941) described the adult female as having the distal third only of the first segment of the hind tarsi black. In two of the specimens bred from Kabale, the whole of the first segment of the hind tarsi is black, except for a small basal yellow ring.

Breeding places.—Shallow swamps containing aquatic plants.

Taeniorhynchus (Coquillettidia) pseudoconopas, Theobald.

LARVA (figs. 1*d*, 4) hitherto undescribed. 4 pelts from Entebbe, Uganda, August, 1944. Only likely to be confused with that of *T. atroapicalis,* from which it may be separated by the antennae and the larger and darker comb spines.

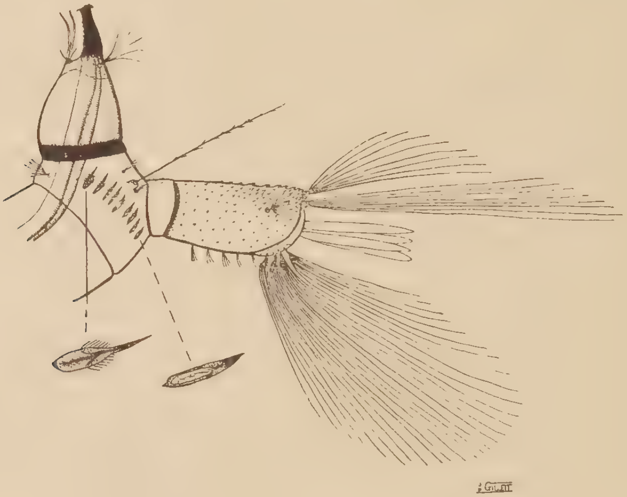

FIG. 4.—*Taeniorhynchus* (*Coquillettidia*) *pseudoconopas,* Theo. Terminal segments of larva.

Length 6-7 mm.; *colour* greenish blue.

Head.—Antennal tuft of about 20 plumose hairs, placed at about $\frac{4}{5}$ (excluding flagellar segment); longer subterminal seta about $\frac{1}{2}$ length of flagellar segment.

Abdomen.—Comb a row of 7-10 large dark sharp-pointed spines, with a basal fringe on most; longer, wider and darker than in all other known Ethiopian species of the subgenus except *T. metallicus.* Tuft B of eighth segment long, single, plumose and arising from a well developed basal tubercle.

PUPA (fig. 2*d*) hitherto undescribed. 4 pelts from Entebbe, Uganda. Only likely to be confused with those of *T. aurites* and *microannulatus,* from which it may be distinguished by its smaller size, and by the shape of the paddles.

Paddles only about 3 times as long as their maximum width; the widest part being about the middle; outer point very slightly longer than inner, sharper and with a tendency to be darkened at the tip.

ADULT.—Edwards (1941) described the adult of this species as having the integument of both thorax and abdomen mainly yellow. All of the 41 wild caught adults taken by the writer in forest in Entebbe, Uganda, July, 1944, and 4 specimens bred from larvae have the integument of both thorax and abdomen distinctly green, the only yellow being on the legs. Haddow (private communication), working in Bwamba on the Uganda-Congo border, has taken a total of nearly 900 adult *pseudoconopas*, all of which have the integument green. Pinned specimens kept for more than a year are grey-green in colour. It is clear that both yellow and green forms exist.

In many of those caught by Haddow, the dark scales of the wings tend to form two transverse bands as in *T. maculipennis*. It is obvious, therefore, that this distinction between *pseudoconopas* and *maculipennis* does not hold as far as Bwamba specimens are concerned.

Breeding places.—Found on the roots of *Thaumastocostus* sp. in a depth of about 2 cm. of water, in dense forest.

Note.—The writer has found that the species in Entebbe bites man freely in forest by day, and Haddow (1945) found that the ratio of those caught feeding by day to those caught feeding by night was 25 : 1 (the ratio being worked out from a collection of 874 wild caught adults).

Taeniorhynchus (Coquillettidia) maculipennis, Theobald.

Larva (fig. 1*b*) described by Gillett (1945), since when 24 specimens (Entebbe, Uganda) have been bred through from fourth-stage larva to adult. It was said to differ from *T. aurites* and *microannulatus* in the antennae only, but it has since been found that there is one more important distinguishing feature, which was missed in the previous description owing to the fact that the larvae of both *T. aurites* and *microannulatus* had been described as having tuft B on the eighth abdominal segment double (Hopkins, 1936). Some 50 *aurites* larvae, including 34 isolations from which adults were bred, and 4 *microannulatus* larvae have been examined and tuft B is single in every case; whereas it is double in *maculipennis*.

The larva of *T. maculipennis* is very easily separated from all other known Ethiopian larvae of the subgenus by the following combination of characters: antennal tuft (as in *pseudoconopas*) at $\frac{4}{5}$ and longer subterminal seta about $\frac{1}{2}$ length of flagellar segment of antenna, but tuft B of eighth abdominal segment double.

Length 5-6 mm.; *colour* pale green.

Head.—Antennal tuft of about 30 plumose hairs placed at about $\frac{4}{5}$ (excluding flagellar segment); longer subterminal seta about $\frac{1}{2}$ length of flagellar segment.

Abdomen.—Tuft B of eighth segment long, plumose and double.

Pupa (fig. 2*j*), described by Gillett (1945). Separable from the other Ethiopian pupae of the subgenus by its small size and by the shape of the paddles.

Paddles long, narrow and tapering; about 4 times as long as their maximum width; outer point about twice the length of the inner.

Adult.—The integument of both thorax and abdomen is described by Edwards (1941) as being yellow. 24 specimens bred from larvae together with numerous wild caught adults from Entebbe and Bwamba taken by the writer in 1944 all have the integument green. Pinned specimens keep their green colour, although they lose some of the brightness.

Breeding places.—In shallow dirty water associated with aquatic vegetation, both in forest and in open lake-side positions.

Note.—The species feeds freely on man by day in forest.

Taeniorhynchus (Coquillettidia) fuscopennatus, Theobald.

Larva (figs. 1*c*, 5) hitherto undescribed. 4 pelts from Entebbe, Uganda, July and August, 1944. Separable by the structure of the antennae from other Ethiopian larvae of the subgenus with tuft B of the eighth abdominal segment double.

Length about 7 mm.; *colour* dirty white with a distinct violet tinge.

Head.—Antennal tuft at about $\frac{3}{4}$ (excluding flagellar segment); longer subterminal seta from $\frac{2}{3}$-$\frac{3}{4}$ length of flagellar segment.

Abdomen.—Tuft B of eighth segment long, plumose and double.

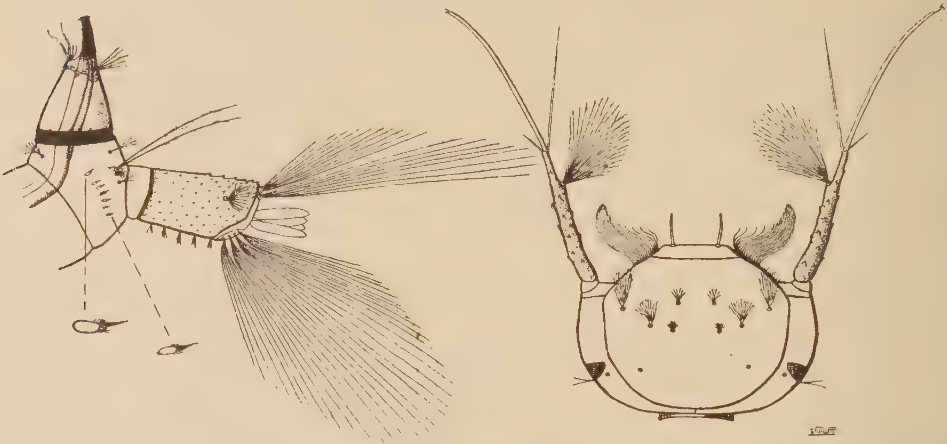

FIG. 5.—*Taeniorhynchus* (*Coquillettidia*) *fuscopennatus*, Theo. Terminal segments and head of larva.

PUPA (fig. 2*h*) hitherto undescribed. 4 pelts from Entebbe, Uganda. The dark colour, large size and long tapering paddles make this pupa just recognisable, if one is used to examining pupae of the subgenus.

Paddles long, narrow and tapering; about 4 times as long as their greatest width; outer point about 3 times the length of the inner; inner margin distinctly concave.

ADULT.—*T. fuscopennatus,* although mainly homophilic, does not confine its biting activities entirely to man. The writer has many times observed the species biting dog, donkey and man, when all three baits have been present at the same time.

Breeding places.—Found with many *T. aurites* in " grassy " swamp.

Notes.—The species appears as a night feeder all through the year in Entebbe. but during times of very heavy infestation it feeds to a lesser extent by day also. This may be due to competition; those unable to find food by night being forced by hunger to seek food in daylight, or it may be due to nearly optimal microclimatic conditions obtaining throughout the day during the dull rainy season, when the heavy infestations occur. A combination of the two explanations is more than likely. In May and June, 1944, Haddow, Gillett and Highton (unpublished), during critical 24 hour catches in forest in Bwamba, took no *fuscopennatus* by day and only 17 by night. Haddow (1945), during critical 24 hour catches carried out by him previously, took 20 *fuscopennatus* by day and 271 by night.

Oviposition has been observed to take place at night, a week after a blood meal. The long narrow raft consists of about 3-4 rows of about 30 eggs each.

Taeniorhynchus (**Coquillettidia**) **aurites,** Theobald.

LARVA (fig. 1*g*) described by Hopkins (1936) and figured by Hansford, but neither the description nor the figure applies to the material examined by the writer, which includes 34 fourth-stage larvae bred through to adult, and some of Hopkins' original material. The antenna has been described by Gillett (1945) when comparing the species with *T. maculipennis*.

The larva is unlikely to be confused with any other Ethiopian larva of the subgenus, except with that of *T. microannulatus,* from which it is impossible to separate it. The position of the antennal tuft, and the length of the longer subterminal seta make these two species unmistakable.

Length about 8 mm.; *colour* variable, dirty blue-white, purplish white and bright green specimens have been taken.

Head.—Very large antenna with tuft at about $\frac{4}{7}$ (excluding flagellar segment); longer subterminal seta nearly as long as the flagellar segment, varying from $\frac{3}{4}$ to $\frac{7}{8}$ its length.

Abdomen.—Tuft B of eighth segment long, highly plumose, single and arising from a well developed basal tubercle.

PUPA (fig. 2*e*) described by Edwards (1941), from 4 pelts. This pupa is only likely to be confused with those of *microannulatus* and *pseudoconopas,* its darker colour makes it separable from the former, and its large size from the latter.

Paddles subject to a little variation, but usually with points about equal, and both margins convex.

Respiratory trumpets with the usual slight bulbous widening in the reticulate portion of the meatus. This is not mentioned by Edwards.

Breeding places.—Shallow " grassy " swamps—very easy to find in Entebbe, compared with the other larvae of the subgenus.

Notes.—When pupating, this insect anchors its pupal trumpets in the root of a plant, and then lets go the larval siphon in the usual way. It then proceeds to " kick " off the larval skin by violent circular movements of its abdomen. In this operation it invariably leaves the cast skin nearly inside out—the siphon and anal segment being drawn through the remainder of the skin until they reach the head capsule, in much the same way as one's socks are prepared for easy putting on. Very often the ventral brush and caudal setae are left sticking into the head capsule. This peculiarity is also found in *T. microannulatus.*

Taeniorhynchus (Coquillettidia) microannulatus, Theobald.

LARVA (fig. 1*g*) described by Hopkins (1936) as indistinguishable from *T. aurites.* Recent material comprising 4 pelts taken by the writer in Entebbe, Uganda, July, 1944, also cannot be separated from *T. aurites.* (See under descriptions of the larvae of *T. maculipennis* and *aurites* above.)

Length about 7 mm.; *colour* grey-blue to dirty white.

Head.—Antennal tuft at about $\frac{4}{7}$; longer subterminal seta from $\frac{3}{4}$ to $\frac{6}{7}$ length of flagellar segment.

Abdomen.—Tuft B of eighth segment long, highly plumose and single.

PUPA (fig. 2*f*) described by Edwards (1941), from 2 pelts. 4 pelts from Entebbe, Uganda, July, 1944, agree with Edwards' description. In the living pupa *T. microannulatus* may be separated from *T. aurites* by the much lighter colour of the former.

Paddles subject to a little variation, but usually with points about equal.

Respiratory trumpet with the usual slight bulbous widening in the reticulate portion of the meatus. This is not mentioned by Edwards.

Breeding places.—Taken together with many *T. aurites* from shallow " grassy " swamps, and by Hopkins in a large papyrus swamp.

Taeniorhynchus (Coquillettidia) atroapicalis, sp. n.

Larva (fig. 1*e*). 15 pelts and 2 whole larvae from Entebbe, Uganda, August, 1944. Only likely to be confused with that of *T. pseudoconopas,* from which it may be separated by the smaller and paler comb spines, by the antennae and by the arrangement of the tufts on the ventral surface of the saddle.

Length 5-6 mm.; *colour* grey-blue to bright green.

Head.—Antennal tuft of about 30 plumose branches at about $\frac{3}{4}$ (excluding flagellar segment); longer subterminal seta about $\frac{2}{3}$ length of flagellar segment, varying between $\frac{4}{7}$ and $\frac{3}{4}$.

Abdomen.—Tuft B of eighth segment long, plumose, single and arising from a distinct basal tubercle. Tufts proximal to barred area on ventral surface of saddle arranged alternately in two rows.

Pupa (figs. 2*b*, 2*i*). 15 pelts from Entebbe, Uganda. Very easily separated from all other Ethiopian pupae of the subgenus by the shape of the paddles, which are quite distinctive.

Paddles very long, narrow and tapering ($4\frac{1}{2}$ times as long as their greatest width), with the outer point 4-6 times as long as the inner.

Adult.—The present description is based on 7 bred males and 8 bred females from Entebbe, Uganda, August, 1944. A bright yellow species resembling, and probably previously mistaken for *T. aurites,* from which it may at once be separated by its black tipped femora and its smaller size.

♀. *Head* yellowish; erect and decumbent scales pale yellow; tori and clypeus orange yellow; proboscis yellow with black tip and narrow black base beneath; palpi yellow with broad black tips (reduced to a few scattered black scales in one specimen).

Thorax.—Integument yellow. Scutum with a scanty covering of bright yellow scales, which are mostly arranged in longitudinal lines. Three patches of white scales on the pleurae; in the middle of the sternopleura, on the posterior margin of the lower part of the sternopleura and on the mesepimeron. Those on the middle of the sternopleura and mesepimeron very much smaller than those in *T. aurites,* and with scarcely any darkening of the integument beneath. A few yellow scales on the scutellum.

Abdomen mainly yellow, but with a few scattered black scales sometimes tending to form black triangles on the posterior margins of tergites 2-4. Small black dots on the posterior corners of tergites 1-6. Sternites mainly yellow, but with black scales tending to form posterior dark bands.

Legs mainly yellow. Femora yellow with numerous scattered black scales (these scales moderately numerous on the apical half only of front and hind femora, but very numerous for the full length of the middle femur) and a *well marked black apical ring.* Front and middle tibiae with numerous scattered black scales, and a black apical ring. These black scattered scales are almost entirely restricted to the anterior surface of the middle tibia, where they generally form an almost complete black line extending for $\frac{2}{3}$ the length of the tibia. Hind tibia with an apical black ring, a black ring just beyond the middle and a few dark scales at the extreme base. Front tarsi with first segment yellow except for black tip; second segment yellow with apical third black; third, fourth and fifth segments all black. The basal half of the third segment is yellow in a few specimens. Middle tarsi all yellow except for fifth segment which is all black; in some specimens there is a slight darkening at the apices of segments 1-4. Hind tarsi yellow with distal $\frac{1}{4}$ of first segment black, distal $\frac{1}{2}$ of second segment black, distal $\frac{2}{3}$ of third segment black, fourth and fifth segments all black. No variation has been observed in the hind tarsi.

Wings all yellow—with occasionally a few scattered dark scales on the sixth vein.

♂. *Ornamentation* as in the female. Palpi mainly yellow; tip of shaft black scaled; distal half of penultimate and whole of terminal segments black scaled; plumes yellow.

Terminalia.—Style (fig. 6) with median membranous expansion very similar to that in *T. aurites.*

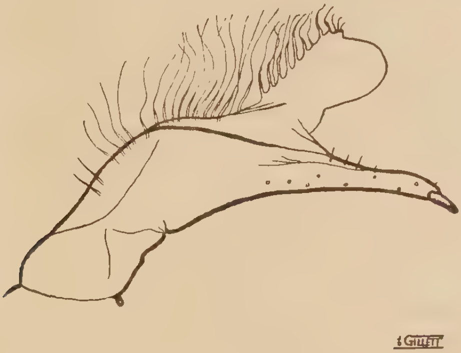

FIG. 6.—*Taeniorhynchus* (*Coquillettidia*) *atroapicalis,* sp. n. Male style.

The types of *T. atroapicalis*, and specimens of the larvae and pupae of all the eight species of *Coquillettidia* dealt with in the present paper will be presented to the British Museum in due course. Specimens will also be presented to the Uganda Protectorate collection and to the London School of Hygiene and Tropical Medicine.

Breeding places.—Found in a shallow "grassy" swamp in thick forest, together with a few *T. maculipennis.*

Acknowledgements.

It is with pleasure that I record here my thanks and appreciation to Mr. G. H. E. Hopkins and Dr. A. J. Haddow for many helpful suggestions, and loan of material, Messrs. Majwega and Kironde who assisted with the catching of the *Taeniorhynchus* larvae and to my wife, who helped with some of the work.

Summary.

Notes are recorded on some of the habits of members of the subgenus *Coquillettidia* of the genus *Taeniorhynchus*, with an account of catching and rearing methods employed. Fourth-stage larvae of eight different species have been caught and successfully reared to the adult stage, four of these for the first time. One new species is included in the list.

Keys are given for larvae and pupae, together with full descriptions of the larvae and pupae of the eight species dealt with.

Errors in the previous descriptions of *T. aurites* and *microannulatus* are pointed out.

References.

DAUBNEY, R. & HUDSON, J. R. (1933). Rift Valley fever.—E. Afr. med. J., **10,** pp. 2-19.

EDWARDS, F. W. (1941). Mosquitoes of the Ethiopian Region III.—Culicine adults and pupae, pp. 90-101, 382-383. Brit. Mus. (Nat. Hist.).

GILLETT, J. D. (1945). The larva and pupa of *Taeniorhynchus* (*Coquillettidia*) *maculipennis*, Theobald.—Bull. ent. Res., **35**, pp. 395-397.

HADDOW, A. J. (1945). On the mosquitoes of Bwamba County, Uganda. II. Biting activity with special reference to the influence of microclimate.—Bull. ent. Res., **36**, pp. 33-73.

HOPKINS, G. H. E. (1936). Mosquitoes of the Ethiopian Region. I.—Larval bionomics of mosquitoes and taxonomy of Culicine larvae, pp. 83-84. Brit. Mus. (Nat. Hist.).

WANSON, M. (1944). Elevage du *Taeniorhynchus* (*Coquillettidia*) *metallicus*, Theobald.—E. Afr. med. J., **21**, pp. 269-272.

WIGGLESWORTH, V.B. (1933). The effects of salts on the anal gills of the mosquito larva; the function of the anal gills of the mosquito larva; the adaptation of mosquito larvae to salt water.—J. exp. Biol., **10**, pp. 1-37.

A REVIEW OF TWENTY-FIVE YEARS OF ECONOMIC ENTOMOLOGY IN THE ISLAND OF MAURITIUS.

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(Plates XIV-XV.)

Introduction.

Mauritius, one of the islands forming the well-known Mascarene Islands, lies in the South Western Indian Ocean between longitude 57° 18′ and 57° 49′ East and latitude 19° 58′ and 20° 32′ South, about 550 miles to the East of Madagascar. The Island is triangular in shape and is 36 miles long and about 23 miles broad with a circumference of 130 miles and an area, including the small islets round the coast, of about 720 square miles. It is of volcanic origin and one can still see the extinct craters near its centre (Grand Basin, Mare aux Vaccas, Trou aux Cerfs). There seem to have been two periods of eruptions of these now extinct volcanoes, the first forming the Black River Mountain Range and the second, mostly composed of basalts and dolerites, the central districts of the Island. There is evidence of a recent elevation of from 40 feet in the South to 12 feet in the North. The rocks are all basic in character and clay slates can be found in the Black River Mountains, while trachyte with platy structure can be found near the centre of the Island (37:141).

The soils of Mauritius (74:295), although originating from the same basaltic magma, differ considerably in character. They can be classified into (1) mature soils or soils derived from old parent rocks; (2) immature soils or soils of more recent formation characterised by the presence of stones and boulders; and (3) cultivated soils which can further be classified into slightly laterised soils and highly laterised soils. Rainfall has been shown by Craig (8) to be the most important factor in determining the composition of the cultivated soils of Mauritius. Slightly laterised soils are found in the dry districts, while in the wet regions, *i.e.*, in the uplands, the soils are mainly of highly laterised types.

Two well marked seasons usually occur in Mauritius, the summer season extending from December to April and the winter season from May to November. While the summer or hot season is generally accompanied by heavy showers and occasional cyclones, the winter or cool period is characterised by dry or semi-dry conditions. The mean annual temperature varies with the season and altitude. Near the coast the mean temperature ranges from 25·5° to 27·0° C. during December to April and from 21·2° to 22·7° C. from May to November. In the uplands, the mean annual temperature varies from 23·3° to 22·0° C. and from 18·8° to 17·8° C. during the corresponding periods. The same variations occur in the rainfall which ranges from 25-75″ near the coast (mean annual rainfall) to 100-175″ in the uplands. The true rainy season extends from December to April with a maximum average precipitation in March.

The most important industry is that of sugar-cane on which the whole population depends. Sugar-cane is usually planted at the close of the winter season, and harvest takes place the year after in July-August or September. The total acreage under sugar-cane in 1940 amounted to 150,845 acres, and the mean yield of canes per arpent during the same year was 24·55 tons. The total sugar production for 1940 amounted to 316,250 metric tons.

Brief Historical Review.

The first entomological problem that confronted the agriculturist in Mauritius was that of the red locust, *Nomadacris septemfasciata*, Serv., which, according to various authors, was periodically the most serious pest encountered up to 1770. In 1762, the Minah bird (*Acridotheres tristis*, L.) was introduced from India by the Comte de Maudave (68:21; 70:54) as a possible predator. This was the first record of the introduction of a predator of an insect pest into Mauritius and led to the successful solution of its first entomological problem. Through the intervention of the Minah bird, the locust threat was gradually reduced until it became negligible in 1770, a fact which was confirmed by Magon de St. Ellier who wrote: " En 1770 cessèrent les ravages des Sauterelles, véritable fléau qui durant plusieurs années, avait arrêté le progrès de l'agriculture. La destruction de ces insectes est attribuée aux martins " (68:22).

In 1850 (7:177; 75:151) the spotted borer of sugar-cane (*Proceras sacchariphagus*, Bojer) was apparently introduced from Java in a consignment of sugar-cane tops. Damage due to this borer was recorded for the first time in the North of the Island in 1850 and subsequently, in about 1856, a committee was appointed, with Wenceslas Bojer (1796-1856) as President, to study the various diseases of sugar-cane and to ascertain the rôle of the borer in Mauritius. A report was published in 1856 in which Bojer described the moth borer of sugar-cane under the name of *Proceras sacchariphagus* (4).

In 1864, Dr. Icery published his " Mémoire sur le Pou à poche Blanche " as a result of his researches on a Coccid attacking sugar-cane which, as he pointed out (25:1), " a causé en maintes localités, de grands degâts et un mal de longtemps irréparable ". Guérin-Méneville subsequently associated Dr. Icery's name with this insect and named it *Coccus iceryi* (1867). It is now known as *Pulvinaria iceryi* (Guér.).

About 1879, *Sesamia vuteria*, Stoll, the pink borer of sugar-cane, was reported in the Mascarenes (12:7) but its presence in Mauritius was not specifically mentioned. Bonâme (5:15; 6:17) worked on it in 1895, and it is therefore evident that it was present in the Island prior to that date; the white borer of sugar-cane, *Argyroploce schistaceana*, Snell., was also present in the Island in 1895 (12:18). The work of Bonâme (5:15-18) prepared the way for d'Emmerez's work on borers (12) in 1916.

At the beginning of the present century, *Clemora* (=*Phytalus*) *smithi*, Arrow, a major insect pest of sugar-cane, made its appearance. This Melolonthid was first recorded in 1911 when it caused much havoc in sugar-cane plantations. The exact date is still uncertain but it is presumed that it was introduced at least five or six years before 1911, *i.e.*, in 1906-1907, probably in earth containing rooted sugar-canes from Barbados. The Department of Agriculture which was created in 1913 and the planters in general spared no effort to control the pest. One of the methods advocated was the hand collection of both adult beetles and larvae. This proved to be of little use, and in 1937-38 hand collection ceased. In 1935, schemes for the large scale introduction of parasites and predators of major insect pests, which had already been started by d'Emmerez de Charmoy in 1913-14 with the introduction of *Tiphia parallela*, Sm., from Barbados and continued in 1917 with that of *Campsomeris coelebs*, Sic., from Madagascar, were pushed further in an attempt to secure more successful parasites. Unfortunately these projects were brought to a standstill in 1939 by the outbreak of war.

From 1913 to 1929, d'Emmerez de Charmoy, as Government Entomologist, had to cope with numerous entomological problems and some of the most important of these he brought to a successful conclusion, *e.g.*, the control of *Oryctes tarandus*, Ol., by introducing *Scolia oryctophaga*, Coq., from Madagascar in 1915; the control of prickly pears by introducing *Dactylopius indicus* from South Africa and *D. tomentosus* from Ceylon in 1913-15 and 1927, respectively; by introducing Scoliid wasps from Barbados and Madagascar to control *Phytalus smithi*, Arr., etc. D'Emmerez de Charmoy died in 1931, and it is the writers' duty to acknowledge here the valuable help which his numerous contributions still render to the Economic Entomology of Mauritius.

The senior author, who has worked for the past 22 years in the Entomological Division of the Department of Agriculture, has been able to follow closely the gradual change in the status of the various insect pests mentioned later. The unpublished notes accumulated during that period by this officer as well as by all other officers of the Entomological Division have been freely drawn upon, with due acknowledgement of the main sources of information.

General Remarks on the biological Control of Insects in Mauritius.

Biological control as a means of combating introduced insect pests was first tried out in 1915 by d'Emmerez de Charmoy in his classical work on the introduction of Scoliid parasites from Madagascar to control *Oryctes tarandus*, Ol. (15). From 1915 to 1939 numerous entomological missions were sent all over the world to search for parasites of major insect pests, and a total of 64 different parasites and predators were introduced, of which 15 species have so far been recovered. The failure of some of these importations has been explained so far as possible in the following paper, but a broad view of the ecological and biological systems of an island like Mauritius shows that biological control of insect pests in insular countries is not as successful as is sometimes advanced in textbooks.

A general survey of the last twenty-five years indicates that apart from all biotic factors, climate is the limiting factor in the control of insect pests by predators and parasites. It has been observed that, under Mauritian conditions, recovery of introduced parasites and predators in the field generally occurs six to eighteen months after introduction and, if no recovery is made after that time, the acclimatisation of the introduced parasite or predator can be considered as having failed. From the evidence given later the conclusion is drawn that successful biological control of insect pests should consist, in future, *not* in seeking for *a* parasite recorded on a particular host in *any* country, but in searching for *the* parasite thriving well in a country with ecological and meteorological conditions similar to those found in Mauritius.

Insect Pests of Sugar-cane.

(*a*) *Clemora smithi* (Arrow)*.

The first outbreak of *Clemora* (=*Phytalus*) *smithi*, Arrow, occurred some 33 years ago in sugar-cane plantations in the northern part of the Island (9:1). Initial damage was reported on about 3,000 acres, out of which 300 were highly infested. From 1911 to 1934, the insect spread over an area of 83,000 acres representing roughly 60 per cent. of the total acreage under sugar-cane (51:436). From 1934 to 1944, *Phytalus* has been recorded over the whole Island, except the Black River district where for some unknown reason it has not established itself.

Table I shows the spread of *Phytalus* in the various districts of the Island.

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* The old, familiar name *Phytalus smithi*, Arrow, has been widely used throughout this paper. L. A. Saylor (1942, Proc. U.S. nat. Mus., **92**, no. 3145, p. 159) has recently erected the genus *Clemora* with *Phytalus smithi*, Arrow, as the genotype.

TABLE I.

District	Years			
	1911	1928	1932	1934
Pamplemousses and Rivière du Rempart	3,000	28,160	36,500	40,000
Flacq	—	3,170	8,200	13,000
Moka and Plaines Wilhems	—	7,380	13,000	17,000
Grand Port and Savanne...	—	3,160	9,300	13,000
Total	3,000	41,870	67,000	83,000

Figure 1 illustrates the gradual spread of the pest since 1911.

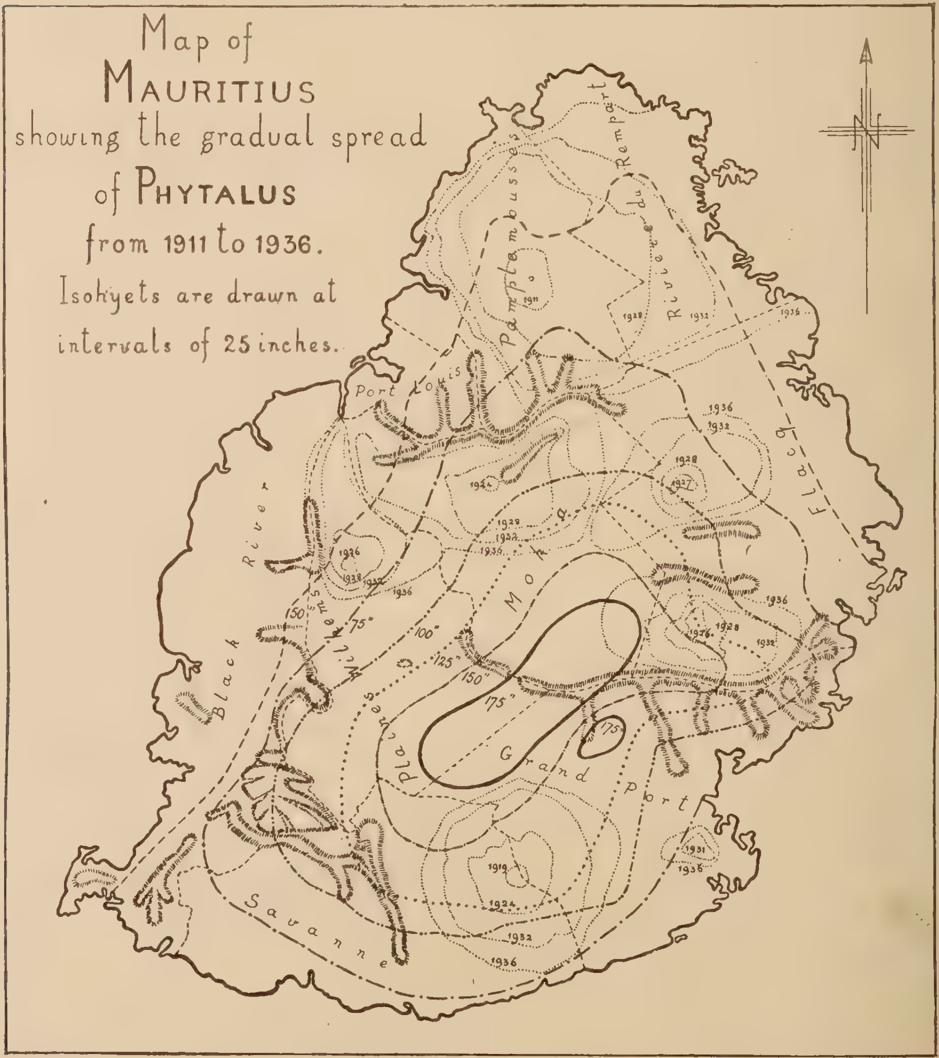
Map of MAURITIUS showing the gradual spread of PHYTALUS from 1911 to 1936.
Isohyets are drawn at intervals of 25 inches.
N
Pamplemousses
Rivière du Rempart
Port Louis
Flacq
Moka
Black River
Plaines Wilhems
Grand Port
Savanne
1911
1924
1927
1928
1931
1932
1936
1919
75"
100"
125"
150"
175"

FIG. 1.

Biology.

The biology of *Phytalus* has been studied by d'Emmerez in 1912 (9:7-13). Further observations on the life-cycle have been carried out since the publication of d'Emmerez's work and figure 2 illustrates the results of these investigations (43:46).

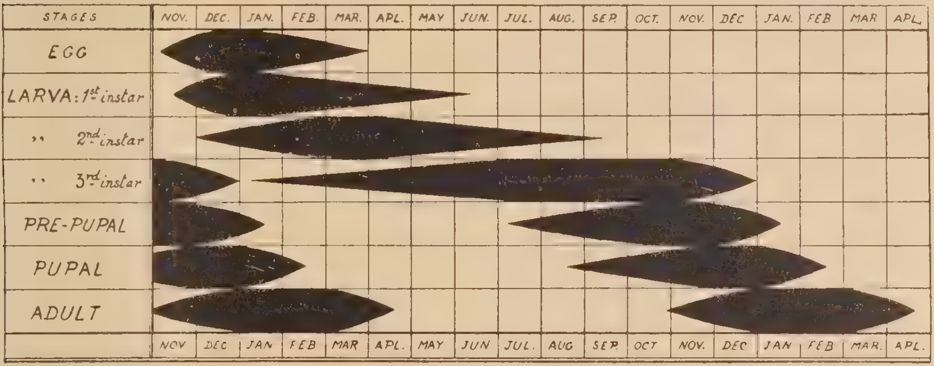

FIG. 2.—Diagrammatic calendar showing the life-cycle of *Phytalus smithi* in Mauritius.

Damage.

Depredations in cane fields are generally noticed when the larval population has reached a figure of about 50,000-60,000 per acre, particularly during the dry season (June-July).

In the early stages of the spread of *Phytalus* in the Island in 1911, it was common to reckon 150-200 larvae per cane stool giving a larval infestation of approximately 300,000 per acre. Such a state of affairs no longer exists: the maximum number of larvae per stool, in heavily infested fields, varies between 25-30, with a population of about 80,000 per acre.

The yield of canes per acre in severely infested fields at the beginning of the spread of *Phytalus* varied from 0 to 10 tons; in 1934, an average loss of 20 per cent. in the yield was reckoned, but this figure dropped to about 10-15 per cent. in 1944. This drop in the loss should be attributed to the planting of *Phytalus*-resistant cane varieties released by the Sugar Cane Research Station, to the work of the introduced parasites and to a better understanding on the part of the planters on how to cope with the pest.

Control.

Few insects of economic importance have been so thoroughly investigated as *Phytalus*, and mechanical, chemical and biological methods of control have been exhaustively explored.

From 1911 up to 1938, the control measures adopted were the hand collection of adult beetles and the digging of larvae. During the same period two Scoliid parasites were introduced, *Tiphia parallela*, Smith, and *Campsomeris coelebs*, Sic. (=*thoracica*, F.) in 1913-14 (13) and 1917 (15), respectively.

Other parasites have been sought from all over the world since 1932 and an officer, Dr. W. F. Jepson, of the Staff of the Imperial Institute of Entomology, together with other officers of the Department of Agriculture were detailed to study the whole problem. Investigations were subsequently carried out from 1932 to 1940 in Madagascar (44; 33:414-415), Puerto Rico (26; 27:6), Philippines (27:13).

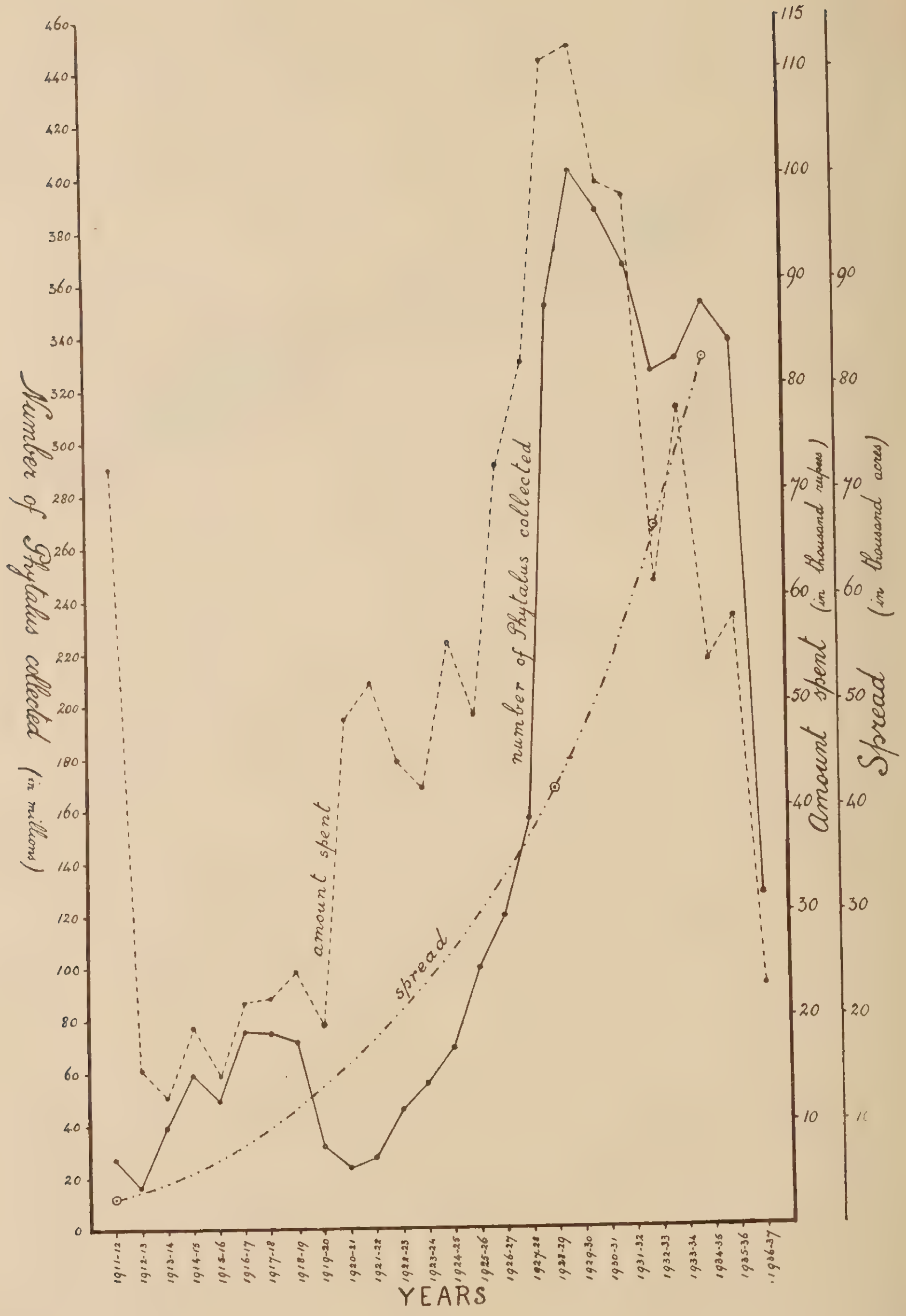

FIG. 3.—Rate of spread of *Phytalus smithi* (1911-1935), the number collected (1911-1937) and the amount spent in that connection.

Java (27:11), Malaya (27:14), South Africa (65), East Africa (57:194), North Africa (57:196-198), England (32:378) and France (57:197). Conjointly with these researches, cessation of hand collection of beetles was recommended in 1937-38. Figure 3 shows the number of *Phytalus* destroyed by hand collection from 1911 to 1938 with the corresponding expenditure. The total number captured and the total amount spent reached the astounding figures of 4,006,620,699 beetles and larvae and Rs. 1,367,086·84 cs. respectively.

Since hand collection was abandoned in 1938, no disastrous results have been experienced; sporadic outbreaks have occurred from time to time but these have generally been closely followed by a satisfactory increase in the number of parasites.

Other measures such as ploughing, forking, subsoiling, trash layering, burning of trash before planting have proved to be of no great value (51:439; 27:8). Experiments with various attractants for the adults were also carried out without great success. Amongst the attractants used were geraniol, eugenol, linalyl acetate, benzaldehyde, essential oil from *Cordia interrupta* leaves, fermented bagass, ether and alcohol extract of female *Phytalus* sexual glands (43:46). Extensive experiments were also carried out with different light traps amongst which various models of the Gourdon type working on the ultra violet ray wave length were used. Results in all cases against *Phytalus* were negative.

Chemical measures were also tried. These consisted in the application of various insecticides such as Cyanogas (in the flake and granular forms) (43:45; 16:10-12; 21:10), paradichlorbenzene (51:442; 16:13), cianidra (51:442; 21:9-10), white arsenic (32:380) and vaporite (16:12-13). The percentage of mortality obtained with these various chemicals was in nearly all cases low as compared with the cost of treatment plus the cost of insecticide involved (32:380; 51:442).

Details of the various parasites that have been introduced (51; 43; 13; 15; 44; 26; 27; 33; 57; 32; 47; 48; 53; 54; 29; 30; 31; 58) are given in Table II; 32 species and varieties of Scoliid wasps have been imported and released.

TABLE II.

Year of importation	Species	Country of origin	Host in country of origin	No. sent	No. recd. alive	% mortality	% hyperparasitism by Conopids§	No. liberated	No. of localities where liberated	Date of first recovery
	HYMENOPTERA : SCOLIIDAE									
1913—14	*Tiphia parallela* ...	Barbados	*Phytalus smithi*	889	38	95·7	—	10	2	v.1916
1917	*Campsomeris coelebs* (= *Elis thoracica*)	Madagascar	*Adoretus* and *Heteronychus*	40	40	0	0	40	1	1920
1917	*C. pfeifferi*	Madagascar	*Encya*	12	12	0	0	12	1	
1932 (1st miss.)	*C. pilosella*	Madagascar	*Enaria*	422	316	25·1	0	256	7	1933
1932 (2nd miss.)	*C. pilosella**	Madagascar	*Enaria*	6,653	2,020	69·6	0	2,020	28	—
1933	*C. dorsata*	Puerto Rico	*Lachnosterna* sp., *Ligyrus tumulosus*	31	18	41·9	0	18	1	—
1934	*C. pilosella*	Madagascar	*Enaria* and *Hoplochelus*	37,177	28,106	24·4	8·5	27,104	77	—
1934	*C. pfeifferi*	Madagascar	?	74	62	16·2	0	55	2	—
1934	*Scolia rubea*	Madagascar	?	347	294	15·2	0	287	10	1938
1934	*Myzine* (*Meza*) *nodosa*	Madagascar	?	166	140	15·7	0	118	1	—
1935—36	*C. erythrogaster* ...	Madagascar	*Hoplochelus*	8,258	5,299	35·8	3·0	3,774	47	1935
,,	*C. javana*	Java	*Leucopholis rorida*, *Euchlora pulchripes*, *Anomala pallida*	4,087	2,485	39·2	8·0	2,384	25	11.ix.1935
,,	*C. annulata*	Java and Philippines	*Holotrichia* sp., *H. vidua*, *Euchlora pulchripes*, *Leucopholis* sp., *Anomala pallida*	6,334	3,620	42·8	39·1	3,323	37	5.viii.1935
,,	*C. quadrifasciata* (= *C. aureicollis*)†	Java and Philippines	*E. pulchripes*, *A pallida*, *Euchlora* sp., *Leucopholis irrorata*, *Stephanopholis philippinensis*, *Holotrichia vidua*, *Lepidiota pruinosa*	12,371	2,139	82·7	33·1	1,430	30	—

,,	*C. lindenii*	Java	*Holotrichia* sp.	214	141	34·1	9·0	77	5	—
,,	*C. phalerata*	,,	*Anomala pallida*	2,199	1,225	44·3	10·6	975	14	27.viii.1935
,,	*C. leefmansi*	,,	*Holotrichia helleri*	31,025	4,089	86·8	7·7	3,558	38	—
,,	*C. marginella modesta*...	Philippines	*Adoretus* sp.	7,739	44	99·4	8·0	37	3	—
,,	*C. quadriguttulata*‡ (=*C. peregrina*)	Java	*Leucopholis rorida* *Euchlora viridis*	873	172	80·3	11·3	145	2	—
,,	*C. asiatica*	Java	?	81	9	88·8	0	2	1	—
,,	*C. rodriguezensis* ...	Rodriguez I.	*Hoplochelus gradaria*	2,840	698	75·4	0	582	10	—
,,	*C. quadriguttulata* var. *sericeps*	Java	*Leucopholis rorida*, *Euchlora viridis*	118	13	88·9	0	7	1	—
1938—39	*C. felina*	S. Africa	?	3,705	1,210	67·3	0 }	2,275	13	—
,,	*C. aureoloides*	S. Africa	?	3,706	1,209	67·3	0 }			
,,	*C. stigma*	S. Africa	?	965	184	80·9	0	106	3	—
,,	*C. mansueta*	S. Africa	?	71	22	69·0	0	22	2	—
,,	*C. lachesis*	S. Africa	?	109	34	68·8	0	34	2	viii.1944
,,	*C.* sp.	S. Africa	?	27	10	62·9	0	10	2	—
,,	*C. barbata*	S. Africa	?	456	45	90·1	0	12	1	—
	DIPTERA : TACHINIDAE									
1935	*Prosena siberita* ...	Java	*Apogonia* sp., *Serica* sp., *Papilia* sp.	8,181 (parasitised grubs)	560	—	—	226	4	—
1935—36	*Urodexia uromyoides* ...	Java	*Holotrichia bidentata*	?	129	—	—	128	5	—
1936	*Paratamiclea pallida* var. *hova*	Madagascar	*Enaria* sp.	50,802	18,690	63·4	—	17,079	17	—
1938—39	*Pexopsis pyrrhaspis* ...	S. Africa	*Hypopholis sommeri*	9,700	2,603	73·1	—	2,482	13	—
1938—40	*Adapsilia latipennis* ...	S. Africa	,,	48,396	654	98·6	—	654	25	—
1937—39	*Dexia rustica*	Europe	*Melolontha melolontha*	1,412	983	30·3	—	53	6	—
1938	*Dexiomorpha picta* ...	Morocco	*Rhizotrogus carduorum*	7,729	4,697	39·3	—	1,137	8	—
1939	*Microphthalma capensis*	S. Africa	*Heteronychus* sp.	12,705	4,963	61·0	—	4,559	6	—

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§ *Conops unicolor* (Madagascar) ; *C. semifumosus*, *C. nubeculosus* and *C. ornatus* (Netherlands East Indies and Philippines).

* Comprises *Campsomeris minutalis*, *C. pocillator* and *C. pilosella*.

† Including also vars. *fimbriata* and *negosicola* of *C. quadrifasciata*.

‡ *C. quadriguttulata* var. *bendoredjoensis* and *C. quadriguttulata* var. *jepsoni* were also included in this lot.

At the time of writing, 9 species of Scoliids have been recovered and at least 4 of these (*Tiphia parallela*, Sm., *Campsomeris coelebs*, Sic., *C. pilosella*, Sauss., and *C. phalerata*, Sauss.) have acclimatised themselves and are commonly found in *Phytalus*-infested areas.

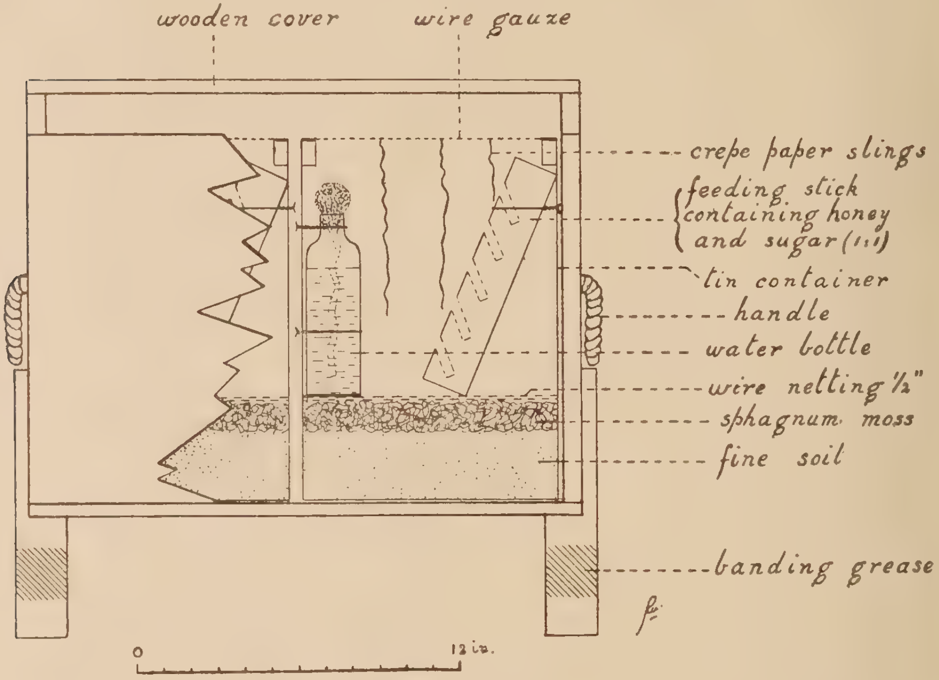

FIG. 4.—Diagrammatic view of shipment cage for Scoliid wasps.

It has been noticed (59 : 15) that there has been a displacement of species of the Scoliids that have established themselves in Mauritius. *T. parallela* and *C. coelebs* have both been displaced by *C. pilosella* and this latter by *C. phalerata*, which is the species most commonly encountered. Also, Scoliids are generally scarce after cyclonic disturbance and it may be 2-3 years before they reappear in normal numbers.

No recovery of the eight species of Tachinids introduced into Mauritius has yet been recorded. The four parasites of adult beetles, *Paratamiclea pallida* var. *hova*, Villen., *Pexopsis pyrrhaspis*, Villen., *Adapsilia latipennis*, Wlk., and *Urodexia uromyoides*, Tns., were liberated in numbers sufficient for colonisation. *P. pallida* var. *hova* is common in Madagascar during the months of June to September, when very few host beetles are to be found in Mauritius. This species parasitises *Enaria* beetles in Madagascar and about 30 per cent. parasitism has been recorded for June 1936. *A. latipennis* and *P. pyrrhaspis* are parasites of the Melolonthid, *Hypopholis sommeri*, in South Africa. Both parasites are also recorded from Zanzibar on *Schizonycha* sp., and on *Anomala plebejus*, Ol., and *Entyposis impressa*, Kolbe, respectively. Regnard (65) obtained the following figures for the parasitism of adult *Hypopholis* by *Adapsilia* and *Pexopsis* at Richmond, Natal (South Africa) in 1937-39. It will be observed that great fluctuations in the parasitism occur from one year to another, the mean parasitism varying from 12·9 per cent. in 1937-38 to 1·5 per cent. in 1938-39.

Month	Percentage parasitism of adult *Hypopholis* by *Adapsilia* and *Pexopsis* (South Africa)	
	1937–38	1938–39
November...	—	2·0
December	23·9	2·1
January	9·9	0·2
February	12·7	2·1
March	5·3	1·4
Mean percentage parasitism	12·9	1·5
Number of beetles examined	59,242	1,235,477

Of the various species of Tachinid parasites of white grubs introduced into Mauritius, *Microphthalma capensis*, Schin., and *Dexiomorpha picta*, Mg., were liberated in the largest numbers. The former is a parasite of *Heteronychus* larvae in South Africa whilst the latter parasitises those of *Rhizotrogus carduorum*, Er., in North Africa. Regnard (65) reports that the mean percentage parasitism of *Heteronychus* by *Microphthalma* in the Cape Province amounts to 34·3, a figure that was obtained from the examination of 12,632 *Heteronychus* larvae. The highest figure obtained by Regnard was 46·7 per cent. parasitism in June, 1939. This figure is very high when compared with that obtained by Moutia (57:201) in Morocco, North Africa. Moutia obtained only 1·5 as a mean percentage parasitism of *Rhizotrogus* larvae by *Dexiomorpha* after examination of 561,000 larvae. It is interesting to note that *Microphthalma* is a parasite of a Dynastid in South Africa, whilst *Dexiomorpha* parasitises a Melolonthid in North Africa.

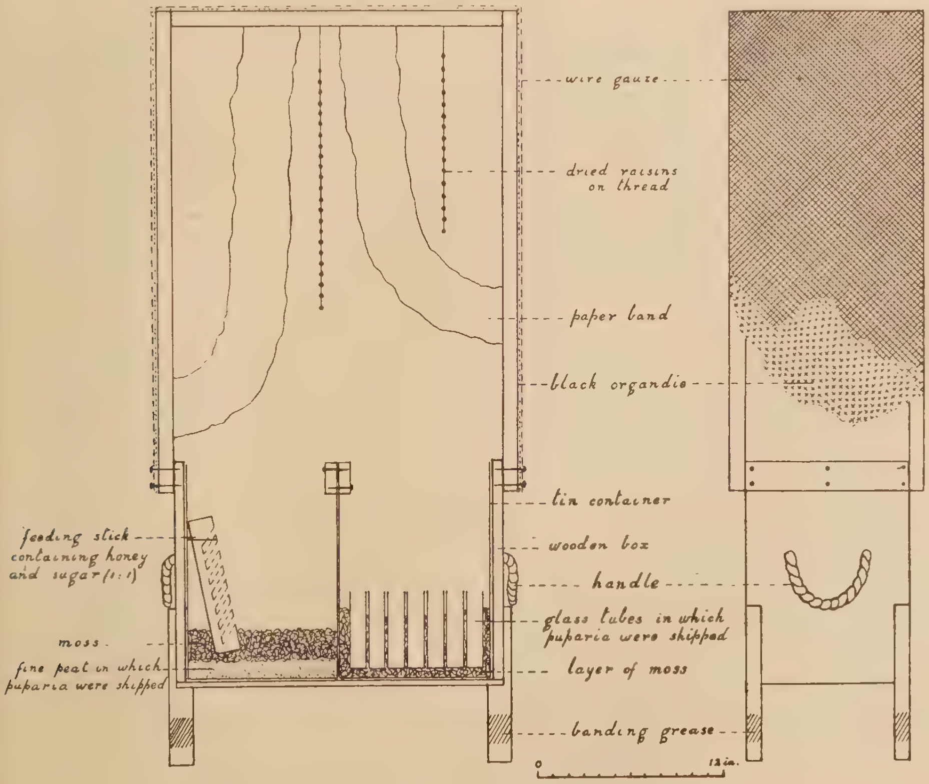
wire gauze
dried raisins on thread
paper band
black organdie
tin container
wooden box
handle
glass tubes in which puparia were shipped
layer of moss
banding grease
feeding stick containing honey and sugar (1:1)
moss
fine peat in which puparia were shipped
0
12 in.

FIG. 5.—View in cross section of shipment cage for Tachinids.

Further details on the importation of Tachinid flies into Mauritius are reported in 57; 26; 27.

Apart from the introduction of the above parasites, entomogenous fungi and various predators have been imported into the Island. Strains of the entomogenous fungi, *Metarrhizium anisopliae* (Metsch.) Sor., *Beauveria bassiana* (Bals.) Vuill., and *B. densa* (Link) Vuill., were imported and mass inoculation of *Phytalus*-infested fields was carried out (43:47; 47:26; 51:443). Results in all cases were negative. Among the imported predators, the giant toad, *Bufo marinus*, L., and the Elaterid, *Pyrophorus luminosus*, Ill., are worth mentioning.

Details of their importation (26:14-17; 27:6; 30:42; 31:17) and liberation are given in Table III.

TABLE III.

Date of importation	Country of origin	Species	No. sent	No. recd. alive	Percentage mortality	Remarks
1938	Puerto Rico	*Bufo marinus*	113	113	0	Of the 113 imported individuals, 80 were liberated in 8 localities. Other liberations from local breeding : Toadlets=286; Tadpoles=620 ; both stages in 14 localities.
1937	Puerto Rico	*Pyrophorus luminosus*	8,309	6,301	24·1	5,196 liberated in 21 localities.

None of the above predators has been recovered, though *Bufo marinus* is known to have acclimatised itself well in other countries, as, for instance, in Hawaii, etc.

Another predator, the Madagascar hedgehog, *Echinops telfairi*, has also been introduced (43:47), but without success: all the imported individuals died in captivity before any release could be made (51:443).

Prior to 1938, two other predators were recorded in Mauritius, the small South African toad, *Bufo regularis*, and the hedgehog. *Centetes ecaudatus*; the former is but a poor feeder on *Phytalus* (6-8 specimens of *Phytalus* were found per stomach) (51:443; 22:7) whilst the latter can hardly be considered of any beneficial value (51:443).

Discussion.

Over 32 species of Scoliid wasps, 8 species of Tachinid flies, 3 species of entomogenous fungi and 2 predators were imported into Mauritius during the period under review in an attempt to secure better control of *Phytalus*. Of these importations, only Scoliids succeeded in establishing themselves; the others were complete failures.

Though it is difficult to assess the causes of the various failures in the biological control of *Phytalus*, the following factors may have contributed.

In the case of the Scoliids, there might have been a lack of synchronism in the periodicity of the host and its various parasites (27:9). There might also have been some intrinsic factors among the Scoliids themselves, as, for instance, the degree of adaptability of host to sting: some were, in fact, found to paralyse their host (*Phytalus*) but no laying occurred. It is evident that, of the large number imported, none has yet shown an adaptability to *Phytalus* comparable with that shown by "*Scolia manilae*" in Hawaii.

The main handicaps to the establishment of the Tachinid flies may have been the following: time of release and the occurrence of *Phytalus* adults not coinciding; inadaptability to climatic factors, in the case of species accustomed to either drier or wetter conditions; specificity to host as for instance a Dynastid parasite introduced to attack a Melolonthid host, *e.g.*, *Microphthalma* on *Heteronychus*, a Dynastid, imported against *Phytalus*, a Melolonthid; absence or shortage of the intermediate host linking the parasitism between main host (*Phytalus*) and parasite (Tachinid), as in other continental regions from where parasites were imported; great fluctuations in the soil texture and rainfall from one region to another in Mauritius; inadequate food supply for adult flies.

The cause or causes of the non-acclimatisation of the giant toad, *Bufo marinus*, L., cannot be explained; breedings from eggs to toadlets were always successfully carried out artificially in specially constructed breeding ponds but the stage from young toadlets to adult toads was generally unsuccessful. Of the initial adult toads liberated in cane fields, rivers, lakes, etc., no recovery of young toads has ever been made. It can hardly be put forward that the insect fauna of Mauritius is not sufficiently rich to satisfy the appetite of the giant toad, in view of the large range of insects that forms its diet in other countries.

The Elaterid beetle, *Pyrophorus luminosus*, suffered the same fate as *Bufo marinus*. Its non-adaptability to Mauritian conditions might have been due to unfavourable climatic factors, particularly the low rainfall in some *Phytalus*-infested areas of the Island, or, to unsuitable food in cane fields for the breeding of its very young larvae.

The attempt to control *Phytalus* by biological means has hardly been as successful as was hoped and the following tentative views on the future of *Phytalus* in Mauritius may be expressed.

Since the cessation of hand collection of adult *Phytalus*, the infestation of cane fields has been no worse than when hand collection was carried out on a basis very near that of a " second industry ". The destruction of 4,006,620,699 adult insects during a period of 26 years did not stop the spread of *Phytalus* in the Island (*cf.* fig. 3). The pest will soon reach saturation point, and this will have a marked effect on the degree of attack which then will be less intense than at the time of hand collection. Such a state of affairs can actually be observed already in some localities. It has moreover been noticed that the sporadic outbreaks which now occur are more easily and quickly reduced to a minimum.

The beneficial work of the Scoliid wasps (particularly of *Campsomeris phalerata*) is always more apparent as soon as a new centre has reached a certain infestation index, when the incidence of the parasite closely follows that of *Phytalus*.

There is still no doubt that *Phytalus* is a major pest of sugar-cane in Mauritius in spite of all efforts to control it by the importation of parasites and predators, but further trials with Tachinid flies should be made, particularly with those species showing a favourable coincidence with the *Phytalus* flight season in Mauritius. Tachinids from Morocco and Java should be introduced in great numbers as a post-war measure of control. Improved air communications which will considerably shorten the delivery of live insects from one region to another will enhance the prospects of success from such importations.

Apart from the biological methods reviewed above, one should not underrate the work of the Sugar Cane Research Station in the breeding of *Phytalus*-resistant cane varieties. If the damage done has reached a phase at which planters are able, to some extent, to cope with the pest, due acknowledgement should be made to the *Phytalus*-resistant cane varieties issued by the Sugar Cane Research Station, of which the most important resistant variety is the M. 134/32.

To sum up, the *Phytalus* problem in Mauritius still demands further efforts to secure better parasites and new varieties of sugar-cane highly resistant to *Phytalus*.

(*b*) *Oryctes tarandus,* Olivier.

This Dynastid was known in the Island as far back as the year 1848 when it was reported as a pest of sugar-cane plantations.

From 1848 to 1911 the damage caused by it was never serious but it regained importance when the new white grub, *Phytalus smithi,* Arrow, was reported in the Island in 1911. The keenness of all planters to search for the new pest in their plantations led to the finding of large numbers of *Oryctes* larvae that otherwise would have remained unnoticed in the cane fields. Robert (66: 452; 67: 512), in 1911, estimated that at least 4,000 acres of cane land were infested with *Oryctes.* Severe damage was sometimes recorded in the North, East, South and Centre of the Island.

From 1911 to 1914, several outbreaks of *Oryctes* were reported in various localities.

At the request of the Chamber of Agriculture, in April, 1917, Messrs. D. d'Emmerez de Charmoy and S. Gébert were entrusted with a mission to Madagascar to search for parasites for the control of *P. smithi* and *O. tarandus.* This resulted in 524 female *Scolia oryctophaga,* Coq., being forwarded in three consignments. Of these 480 females were received alive, giving a low mortality rate of 8·4 per cent. All these live individuals were liberated in three highly *Oryctes*-infested localities. This Scoliid wasp was, at that time, recorded as a parasite of *O. radama,* Coq., *O. ranavalo,* Coq., and *O. simiar,* Coq., in Madagascar (15: 245-254).

The introduction into Mauritius of *S. oryctophaga* against *O. tarandus* proved to be successful, for, in August-September, 1918, that is, one year after its first liberation, a few females were recorded at their places of liberation. It was thus proved that *S. oryctophaga* had acclimatised itself in Mauritius and would readily breed on *O. tarandus* larvae.

From 1914 to the present date, the economic importance of *O. tarandus* has been so reduced that it can no longer be considered a major pest of sugar-cane in Mauritius. Sporadic infestations are sometimes recorded, but in nearly all cases these are associated with an unusually long spell of dry weather in localities where rainfall is generally abundant and well distributed the whole year round.

S. oryctophaga is now of common occurrence in the Island, particularly during the months of July to September. There is no doubt that the decrease in the infestation of *Oryctes* is due to the introduction of this Scoliid, but the extent of this control has never been worked out.

Apart from *S. oryctophaga,* as a natural enemy of *Oryctes* in Mauritius, no other biological factors of importance in the control of this white grub are recorded in this Island. The green muscardine fungus (*Metarrhizium anisopliae* (Metsch.) Sor.) is seldom found attacking *Oryctes* larvae in the field, but the degree of attack is so low that one can hardly consider that it exerts any influence.

(*c*) The Moth Borers of Sugar-cane.

During the period 1848-1897, the sugar-cane planters of Mauritius had to face the threat of three important species of moth borers, the spotted borer (*Proceras sacchariphagus,* Bojer), the pink borer (*Sesamia vuteria,* Stoll) and the white borer (*Argyroploce schistaceana,* Snell.), of which the first two were considered most harmful.

From 1897 to 1937 outbreaks of spotted and pink borers were reported and the damages sustained were sometimes very heavy, particularly when years of severe dryness were experienced.

At the present time, the main borer pest of sugar-cane is the spotted borer and this species will consequently be dealt with more fully in the present paper.

(1) *Proceras sacchariphagus,* Bojer (Spotted Borer).

This borer has been known in earlier reports as *Diatraea sacchariphagus,* Bojer, *D. venosata,* Walker, and *D. mauriciella,* Walker. W. H. T. Tams (71:67) has lately reviewed the synonymy of this species, and it is now known as *Proceras sacchariphagus,* Bojer (1856).

The biology has been fully worked out by d'Emmerez de Charmoy (12:14-15) and Moutia (46:34-36). At least three generations a year have been observed in the field (59:17).

Damage.

In 1914 and 1915, d'Emmerez de Charmoy recorded 22 per cent. of sugar-canes injured by the spotted borer (12:16). Surveys carried out in different localities from 1928 to 1931 showed the following infestation figures (46:34).

TABLE IV.

Years	Mean Stalk Infestation					
	Varieties					
	White Tanna	D.K. 74	M. 131	M. 55	R.P. 8	D. 109
1928	8·0	16·5	12·4	9·4	—	—
1930	17·0	31·7	25·9	31·9	31·0	56·0
1931	28·0	39·0	38·0	38·0	39·0	77·0

Figures for the years 1932-1936 are not available; but, as from 1937, regular surveys were made particularly in heavily infested localities and the percentage joint infestation was then taken into account.

Table V shows the results of these surveys (29:43; 30:44; 31:17).

TABLE V.

Varieties	Mean Stalk Infestation						Mean Joint Infestation					
Years	1937	1938	1939	1940	1941	1942	1937	1938	1939	1940	1941	1942
White Tanna	24·1	20·2	11·9	49·5	—	—	9·5	8·1	9·2	6·2	—	—
B.H. 10/12	25·1	23·3	14·0	98·1	85·2	83·4	9·6	8·7	10·4	32·5	20·9	17·4
M. 134/32	—	—	—	98·8	88·1	96·4	—	—	—	39·3	21·6	21·6

From the year 1937, the sugar-cane variety White Tanna was gradually replaced by the variety B.H. 10/12 and this latter is now being superseded by variety M. 134/32. B.H. 10/12 showed a steady increase in infestation from 1937-1942 but the more recent variety M. 134/32, released by the Sugar Cane Research Station in 1937, though heavily attacked by the spotted borer showed a greater yield per acre as compared with B.H. 10/12. In a survey carried out in 1940, the average yield of some infested M. 134/32 cane fields was reckoned to be 30 tons per acre whilst that of B.H. 10/12 was only 7 tons per acre. It is now generally assumed that the drop in yield in heavily infested B.H. 10/12 virgin canes may reach a figure as high as 50-60 per cent. In first and second ratoon canes the attack of the spotted borer is generally less severe and the drop in yield may be estimated to range from 6 to 10 per cent. The loss in the sucrose content of the cane must also be added to the losses incurred in the fields as well as the injurious effect of red rot, a fungous disease that generally follows attacks of borers.

Control.

The methods of control employed against the spotted borer in Mauritius have been discussed by Moutia (46:38-40) under the following headings:—

(i) Destruction of eggs and larvae by means of trap plants;
(ii) Destruction of larvae by hand collection;
(iii) Straw burning;
(iv) Destruction of injurious grasses and weeds that harbour the pest;
(v) Rotation of crops and interline cultivation;
(vi) Breeding of parasites;
(vii) Selection of borer-free tops for planting.

Apart from the breeding and importation of parasites, none of these methods has proved to be particularly effective.

In view of the prevalence of the spotted borer during recent years, a search for new parasites in Ceylon and Madagascar was carried out with financial aid from the Colonial Development Fund. The first investigation was carried out in Ceylon in 1938-39 (76) and the second in Madagascar in 1940. As a result the following parasites were introduced from these two countries (31:19):—

Table VI.

Origin	Insect imported	No. imported	No. received alive	% mortality	Remarks
Ceylon ...	*Bracon albolineatus*	759	200	73·7	Imported as pupae and adults.
Ceylon ...	*Xanthopimpla stemmator*	58	47	19·0	Imported as adults.
Ceylon ...	*Trichospilus pupivora*	ca. 21,500	18,000	ca. 16·3	Imported as host pupae.
Ceylon ...	*Trichogramma evanescens*	ca. 15,000	5,000	ca. 66·7	Imported as egg parasites.
Madagascar ...	*Euvipio rufa*	No data available	245	—	Imported as adults and host larvae.

Other projects were under consideration for the introduction of parasites from Java and New Guinea, but owing to the outbreak of war, these had to be postponed.

Mass breeding of *Bracon albolineatus* and *Trichospilus pupivora* was carried out in the laboratory, and 2,500 *B. albolineatus* were liberated in 12 infested localities and 275,000 *T. pupivora* in various cane fields, tobacco plantations and lawns. Neither of these two species has been recovered since (31:17-18; 58:15).

Xanthopimpla stemmator was the only parasite recovered from the species introduced from Ceylon. Though this species was sufficiently abundant in 1940 to permit subsequent collection and liberation in infested fields, it became scarce in 1941 and so rare in 1942 (58:15; 59:17; 60:15), that it could not be distributed to planters on the fairly large scale of 1940-41. In view of the above, this parasite can hardly be expected to exercise effective control of *Proceras* in Mauritius.

The Malagasy parasite, *Euvipio rufa*, has not yet been recovered. Projects to introduce it in fairly large numbers were in hand but had to be postponed on account of the war.

The egg parasite, *Trichogramma evanescens,* has been bred on a large scale since its introduction from Ceylon, and was subsequently liberated in heavily borer-infested cane fields. From 1939-1941, a total of 1,530,000 parasites were liberated in a small experimental plot of about 50 acres (59: 15-16). No sign of parasitism was detected, nor was there any significant difference in borer infestation in experimental and control plots. The mass breeding and mass liberation were therefore discontinued in 1941 (59: 16).

A second series of experiments was conducted in 1941-42 in three different heavily infested localities with the local species of *Trichogramma, T. australicum,* Girault (59: 17; 60: 13-15; 63: 13). Mass breeding of this parasite was undertaken with *Corcyra cephalonica,* Staint., and *Sitotroga cerealella,* Ol., as intermediate hosts, and over 1,000,000 parasites were liberated in the experimental fields, with a mean of 15,500 parasites an acre.

Borer surveys were carried out in the fields under experiment before and after the liberation of *T. australicum* and the following results obtained:—

TABLE VII.

Locality No.	Variety	Average Stalk Infestation		Average Joint Infestation	
		Before liberation (1940)	After liberation (1942)	Before liberation (1940)	After liberation (1942)
1	B.H. 10/12 (ratoons) ...	77·0	79·0	15·0	13·4
2	B.H. 10/12 (virgins) ...	94·2	83·4	22·8	17·4
3	B.H. 10/12 (virgins) ...	89·2	22·7	19·9	1·1

The mass liberation of *Trichogramma* in localities (1) and (2) had little effect on the borer infestation, but in locality (3) a marked decrease was noticed. The general impression gained from these experiments is that the results obtained were very erratic and that no definite conclusion can be drawn from them.

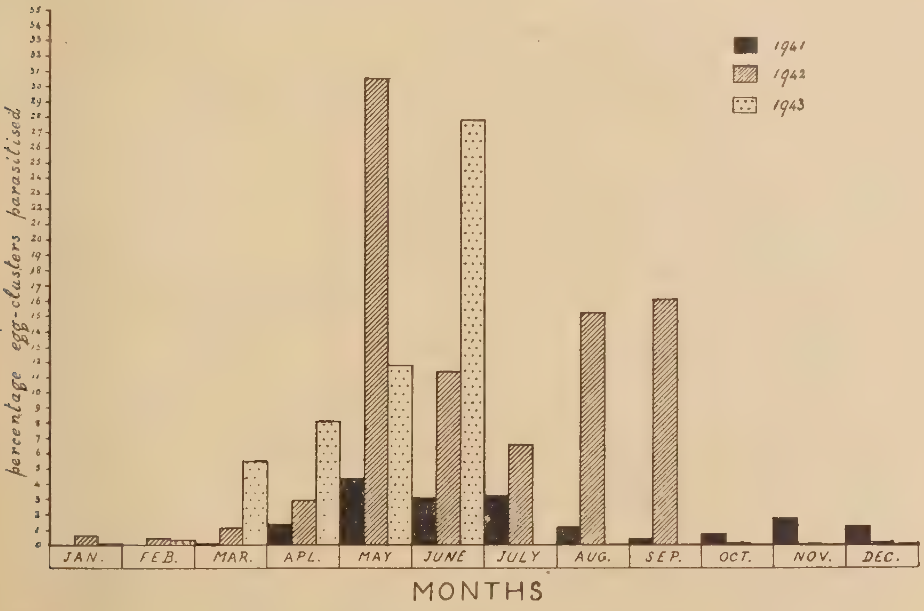

FIG. 6.—Monthly parasitism of egg clusters of *Proceras sacchariphagus* by *Trichogramma australicum* during the period March, 1941 to June, 1943.

The incidence of parasitism of *Proceras* eggs by *T. australicum* has also been worked out, and this is shown in fig. 6. The mean number of eggs per egg cluster was found to be 23·4 and the highest percentage of egg batches parasitised by *T. australicum* reached 55·1. This figure may vary from year to year and the period of maximum parasitism of *Proceras* eggs by *T. australicum* was found to be during the winter season, *i.e.*, from April to September. The factors governing the incidence of *Trichogramma* in Mauritius may be: (1) the heavy rainfall which occurs during the summer season and (2) the cyclonic winds which may prevail during the same period.

Other parasites of *P. sacchariphagus* were recorded in 1916 by d'Emmerez de Charmoy (12:17) in Mauritius: *Prophanurus alecto,* Crwf. (=*Telenomus* sp.), an egg parasite; *Henicospilus antakarus,* Sauss.; *Stauropodoctonus mauritii,* Sauss.; *Apanteles flavipes,* Cam., and a Tachinid fly (sp. indet.), all of which are larval parasites. At the time of writing, no extensive work on the status of these various parasites has been done.

Surveys carried out every now and then since 1938 have shown that *Prophanurus alecto* can hardly be considered as an egg parasite of *Proceras sacchariphagus* for not a single egg was found parasitised out of a total of 840,973 *Proceras* eggs collected during the period 1941 to 1943.

The Ichneumonids, *H. antakarus* and *S. mauritii,* have also not been observed as parasites of *Proceras* larvae and can hardly be regarded as potential enemies of this moth borer in the field.

Apanteles flavipes, another recorded larval parasite of *Proceras,* can be considered as a seasonal enemy; parasitism may sometimes reach 30-40 per cent., especially during the summer months, but owing to its erratic occurrence it is of no great value.

The Tachinid fly, referred to by d'Emmerez de Charmoy in 1916 (12:17), has never been met with in the extensive surveys that have been carried out since that date. The predatory ant, *Pheidole megacephala,* F., was found to be very common in some heavily infested localities; its presence in such infested fields did not prevent the steady yearly increase in borer infestation and this predator may be considered as being of secondary importance.

As well as these parasites and predators, another Ichneumonid parasite, *Xanthopimpla citrina,* has been recorded since 1934. This species has probably been introduced from Madagascar but no exact data are available.

(2) *Sesamia vuteria,* Stoll (Pink Borer).

This moth borer, formerly an important pest of sugar-cane, can now be considered a minor pest in Mauritius. In 1915, d'Emmerez (12:19) recorded that, out of 130,000 borers collected in young cane fields, 96·9 per cent. were *Sesamia,* whilst *Argyroploce* (white borer) and *Proceras* (spotted borer) were represented by 2·5 per cent. and 0·6 per cent. respectively. In 1939, the same figures calculated on 393 borers gave: *Sesamia* 12·7 per cent.; *Proceras* 25·5 per cent. and *Argyroploce* 61·8 per cent.

Few outbreaks have been reported during the past ten years, and these have been confined to years of severe dryness. The rarity of *Sesamia* can be explained by the fact that it is heavily parasitised by the Ichneumonids, *Henicospilus antakarus* and *Stauropodoctonus mauritii.* D'Emmerez de Charmoy has recorded as high a mortality rate as 60 per cent. due to *Henicospilus* (12:25): It is not uncommon to notice swarms of this parasite at dawn on *Cordia interrupta* plants bordering cane fields.

The biology and ecology of *Sesamia* have been studied by d'Emmerez (12:7-10) in 1916.

In an experiment to determine the mortality of shoots due to borer (*Sesamia* and *Argyroploce*) attack and to various other causes, Evans (23: 20-21) found that 89·7 per cent. of dead hearts were killed by borers. Out of 610 shoots formed during the course of the experiment, 326 survived, giving thus a survival rate of 53·4 per cent. The percentage of dead shoots amounted to 46·6 of which 41·8 per cent. were due to borer attack. The percentage of tillers destroyed by borers would appear, at first sight, to be rather high, but, as the rate of tillering is greatly enhanced by the attack of borers, especially on the cane varieties newly released by the Sugar Cane Research Station, the effect of borer attack is thereby greatly reduced.

(3) *Argyroploce schistaceana*, Snell. (White Borer).

D'Emmerez de Charmoy (12: 18-20), who worked out the biology and status of this species, found that it is present, together with the spotted and pink borers, in varying proportions in young cane fields. The following figures, calculated on 130,000 borers, are quoted by that author: Spotted borer (*Proceras*), 0·6 per cent.; Pink borer (*Sesamia*), 96·9 per cent.; White borer (*Argyroploce*), 2·5 per cent. In considering the above proportions, it is evident that *A. schistaceana* was at that time (1915) a minor pest of sugar-cane. No severe outbreak of this borer has since been recorded and, at the time of writing, it causes only negligible harm to young cane plantations.

Aspidiotus destructor, Signoret (Coconut Scale).

This Diaspidid scale was first recorded in Mauritius by d'Emmerez de Charmoy (14: 17) on guava plants (*Psidium guajava*) in 1922. It was first observed on coconut palms, causing no serious damage, at Pointe aux Sables in 1925 (17: 1), but by 1927 it had become a threat to the coconut plantations all over the Island. It was not uncommon at that time to find numerous plants dying from the attack; at Pointe aux Sables, for instance, over 50 per cent. of the plants were found dying in some plantations and a similar state of affairs prevailed in other parts of the Island (Pl. XIV, figs. 1 and 2). The control suggested was to cut and burn infested leaves, after five or six days, when any parasites and predators had emerged. The application of various proprietary banding greases was also suggested to prevent the young larvae dropped from infested leaves crawling from the soil to other plants. Such measures, however, were found to be ineffective since the pest continued to cause appreciable damage. The parasites recorded on *Aspidiotus* at the start of the infestation were *Aphelinus chrysomphali*, Mercet, and *Aspidiotiphagus citrinus*, Craw (Hym., Aphelinidae), as well as the predatory Coccinellid beetles: *Exochomus laeviusculus*, Wse., *Lindorus lophanthae*, Blaisd., and *Cybocephalus* sp. Though the above-mentioned Aphelinids parasitised over 28·2 per cent. (mean) of the scale, the latter still made progress despite constant attacks by the various predators and parasites. Owing to the poor results obtained with the local predators and parasites, it was decided in 1937 to import others from countries where *Aspidiotus destructor* was recorded as a pest of coconut. Arrangements were therefore made to introduce Javanese Coccinellids, *Chilocorus politus*, Muls., and *Scymnus* sp. Through the kind co-operation of Dr. P. Van der Goot, of Java, a first consignment of the above insects was received in May, 1937. Of this consignment, 347 *C. politus* and 152 *Scymnus* sp. were liberated (55). Three months afterwards *C. politus* was recovered in fairly large numbers at its place of liberation. Following this first consignment, four more were received from Java.

Table VIII gives details of the importations.

TABLE VIII.

Consignment No.	Date sent from Java	Date received in Mauritius	Species of Coccinellid	No. of Coccinellids sent from Java	No. of Coccinellids received		% received alive
					alive	dead	
1	13.3.37	24.3.37	*Chilocorus politus*	190 (pupae)			
				490 (adults)	347 (as adults)	333	51·0
			Scymnus sp.	50 (pupae)			
				400 (adults)	152 (as adults)	298	33·8
2	11.12.37	24.12.38	*C. politus*	100 (pupae)			
				700 (adults)	600 (as adults)	200	75·0
			Scymnus sp.	200	64	136	32·0
3	30.12.37	13.1.38	*C. politus*	200 (pupae)	79	121	39·5
				400 (adults)	299	101	74·7
			Scymnus sp.	210	42	168	20·0
4	28.1.38	10.2.38	*C. politus*	240 (pupae)	235	5	97·9*
				860 (adults)	644	216	74·9*
			Scymnus sp.	200	146	54	73·0*
5	28.2.38	15.3.38	*C. politus*	298 (pupae)			
				750 (adults)	1,020 (as adults)	28	97·3*
			Scymnus sp.	25 (pupae)			
				275 (adults)	149 (as adults)	151	49·6*
TOTAL : 5 consignments (March, 1937 to March, 1938)			*C. politus*	928 (pupae)			
				3,300 (adults)	3,224 (as adults)	1,004	76·2
			Scymnus sp.	75 (pupae)			
				1,285 (adults)	553 (as adults)	807	40·5

* Shipped in 5-litre bottles with sugar and moisture.

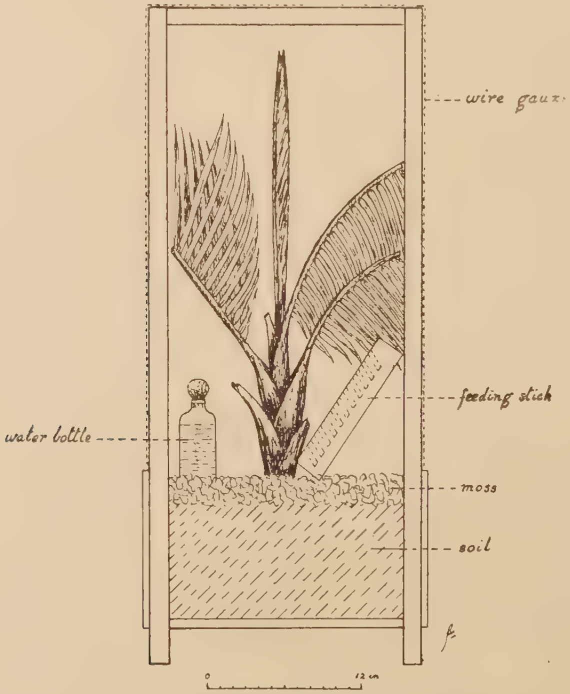

FIG. 7.—Cross section view of shipment cage for *Chilocorus* and *Scymnus* (1st mode of shipment).

Two methods of shipment were used. The first consisted in sending young coconut plants previously infested with *Aspidiotus* in cages measuring 21 ins. long by 22 ins. broad by 50 ins. high. Each cage was lined with fine-mesh wire gauze, and feeding sticks, containing granulated sugar and water bottles, plugged with cotton wool, were fixed in them (fig. 7). These materials helped to supplement the food supply, other than *Aspidiotus*, and provide an adequate supply of water. The second method, which gave the best results, consisted in sending the Coccinellids in large glass jars (6 ins. diameter × 12 ins. long) contained in wooden cases 17 ins. long by 16 ins. broad by 11 ins. high. Granulated sugar and a moist cotton pad were fixed in the jars by means of sealing wax. The mouth of the jar was closed with a lining of fine organdie maintained in position by means of a rubber band (fig. 8). As no green leaves were present, excess of moisture, as well as moulds, was eliminated, and this considerably reduced the mortality in transit (approx. 13 days).

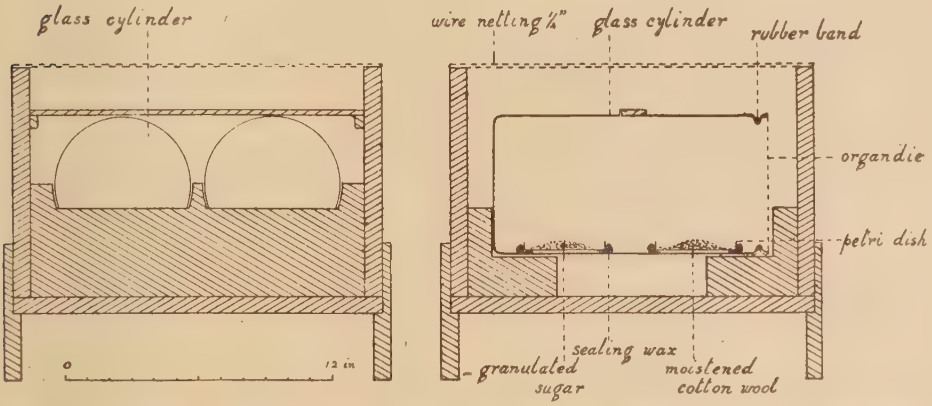

FIG. 8.—Cross section view of shipment cage for *Chilocorus* and *Scymnus* (2nd mode of shipment).

Chalcid parasites were also introduced from Java. Only one shipment was received on 5.x.1938. It consisted of:—

Chiloneurinus microphagus, Mg.	27	individuals	received.
Spaniopterus crucifer, Gah.	50	,,	,,
Comperiella unifasciata, Ishii	8	,,	,,

These parasites were released at Barkly Experimental Station, on 5.x.1938, on an infested coconut leaf and, up to the time of writing, no recovery of these species has been made.

In 1939, an opportunity was taken to introduce the Ceylonese *Aspidiotus* predator, *Chilocorus nigritus*, Muls. Every effort had been made to obtain this predator from Ceylon since 1927 but, owing to its scarcity, no shipment could be made. In May, 1939, however, 111 live individuals were imported and liberated and in April, 1940, it was recovered in large numbers at Barkly Experimental Station.

Before considering the actual status of *A. destructor* in Mauritius, a review of its life-cycle and that of its predators and parasites will be of interest.

The following table gives the life-cycle of *A. destructor* in Fiji (72:5) and Mauritius (29:43).

TABLE IX.

Life-cycle of *Aspidiotus destructor*.

MALES :	Fiji (days)	Mauritius (days)
Egg: incubation period	8	7
Larva : 1st Instar	10	13
2nd Instar	6·5	4
Pupal period	5	4
Adult under scale	2	4
Total (oviposition to emergence from scale)	32	32
Mean temperature	26·1°C.	20·9°C.
FEMALES :		
Egg : incubation period	8	7
Larva : 1st Instar	8·75	13
2nd Instar	9·5	8
3rd Instar preoviposition	8·5	7
Total (oviposition to maturing female)	34·5	35
Mean temperature	26·1°C.	20·9°C.

Predators.

Since the Coccinellid, *Cryptognatha nodiceps*, Mshl., has proved to be an excellent predator of *A. destructor* in Fiji (72), a comparison of its life-cycle with that of the two imported *Chilocorus* spp. in Mauritius (62) will be of interest.

TABLE X.

Comparison between the Life-cycle of *Cryptognatha nodiceps* in Fiji and of *Chilocorus politus* and *C. nigritus* in Mauritius.

Stages	*Cryptognatha nodiceps* in Fiji (days)	*Chilocorus politus* in Mauritius (days)	*Chilocorus nigritus* in Mauritius (days)
Egg : Incubation period	5—6	9—10	9·5—10·5
Larva : 1st Instar	2—3	3	2·5
2nd Instar	2—3	3	2·5
3rd Instar	2—3	3	3·5
4th Instar	4—6	4·5—5·5	5—6
Pupal stage	4	5·5—6·5	5·5—6·5
Total life-cycle	19—25	28—31	28·5—31·5
Mean temperature	26·1°C.	24·5°C.	24·5°C.

Though the *Chilocorus* spp. have longer life-cycles than the *Cryptognatha*, they have proved as effective in Mauritius as the latter, in Fiji, in the control of *A. destructor*. No competition seems to occur between *C. politus* and *C. nigritus*, their life-cycle being nearly the same. In the field, it is sometimes very common to observe *politus* and *nigritus* together in large numbers. Moreover, both species, having a wide host range in Mauritius, can compare favourably with *C. nodiceps* in Fiji. These two predators are also the most effective enemies of the sugar-cane scale, *Aulacaspis tegalensis*, Zehnt., in Mauritius (62) and in addition they are commonly found feeding on many other Diaspidid scales, *Pseudaulacaspis pentagona*, Targ., *Chrysomphalus diversicolor*, Green, *Chrysomphalus dictyospermi*, Morg., *Hemiberlesia simplex*, de Charm., *Diaspis bromeliae*, Kern., etc.

Parasites.

Unlike other countries, in Mauritius *A. destructor* has only two Chalcid parasites, *Aphelinus chrysomphali*, Mercet, and *Aspidiotiphagus citrinus*, Craw. The mean percentage parasitism (worked out in 1930 and 1931) by *Aphelinus* in Mauritius was 25·8 with a maximum of 60·8 per cent. and a minimum of 1·0 per cent. whilst, in the Dutch East Indies, the highest figure obtained (according to A. Reyne, *in litt.*) is 30 per cent. and in Fiji (according to Taylor, *loc. cit.*) the mean percentage parasitism reaches only 5 per cent. The incidence of the parasitism by *Aphelinus* is at its peak during March (cf. fig. 9).

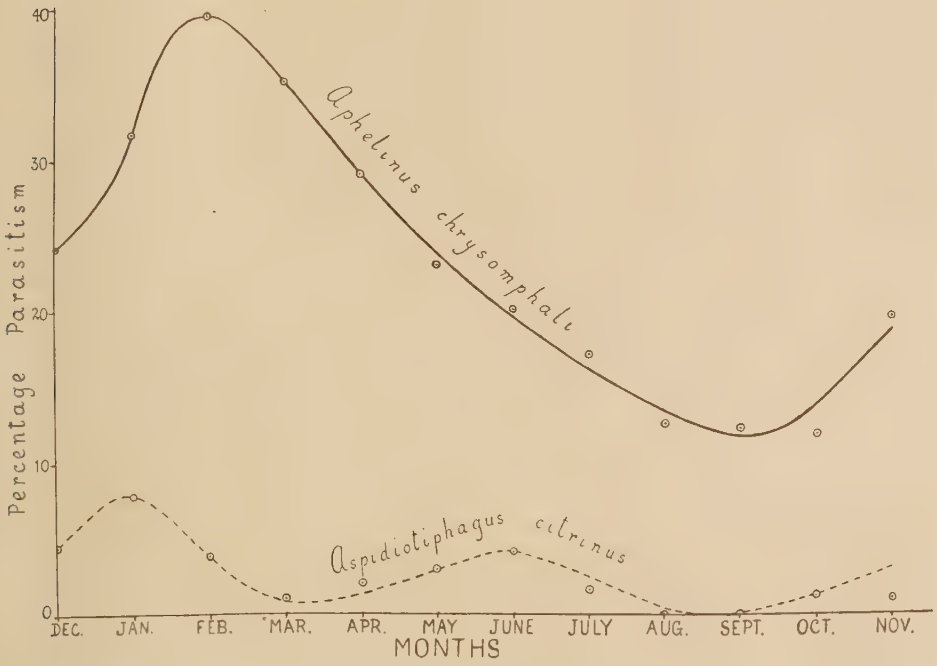

FIG. 9.—Mean monthly parasitism of *Aspidiotus destructor* by *Aphelinus chrysomphali* and *Aspidiotiphagus citrinus* during 1930 and 1931.

A. citrinus is an erratic parasite of *A. destructor*. It was not recorded by Taylor (72: 16) as a natural enemy of this scale in Suva (Fiji) whilst, in Muanicula (Fiji), its highest parasitism reached 5 per cent. In Mauritius the mean percentage parasitism amounts to 2·64 per cent. and the highest 23·2 per cent. but A. Reyne (*in litt.*) estimates a parasitism of more than 50 per cent. in the Dutch East Indies.

Actual status of *Aspidiotus destructor* in Mauritius.

Sporadic outbreaks of the scale do sometimes occur, but, as soon as the scale population has reached a certain density, predators are generally found in such abundance that the infested plants are very quickly cleaned up.

The threat to the coconut plantations has gradually disappeared since 1937 due, no doubt, mainly to the introduced Coccinellids, *Chilocorus politus* and *C. nigritus* (Pl. XIV, fig. 3, and Pl. XV, fig. 1). Plantations which, prior to the above date, were severely attacked with no signs of recovery are now flourishing and in full bearing (59: 19).

It is safe to say that the importation of *Chilocorus politus* and *C. nigritus* has been most successful in the control of *A. destructor* on coconut in Mauritius. This example of biological control can be favourably compared with that of *Cryptognatha nodiceps* on the same scale insect in Fiji or of *Rodolia cardinalis,* Muls., on the fluted scale (*Icerya purchasi,* Mask.) in California.

The Cochineal Insects of Prickly Pears.

Dactylopius indicus, Green.

Dactylopius tomentosus, Lamarck.

Two species of prickly pears are recorded in the Mauritian flora, *Opuntia monacantha,* Haw., and *O. tuna,* Mill. Both species were most probably introduced about a century ago, either as ornamental plants or as food plants for the breeding of cochineal insects for dye production.

During the first decade of the present century, these plants had developed to such an extent that they seriously threatened the pasture lands. In 1913-15 attempts were made by d'Emmerez de Charmoy (18:264) to introduce an Indian strain of cochineal insect from South Africa, *Dactylopius indicus,* Green. This insect thrived so well on *Opuntia monacantha* that by 1928 it had almost completely cleared the Island of it. It was subsequently noticed by d'Emmerez that *D. indicus* could not live on the other species of prickly pear, *O. tuna*.

As a result of correspondence exchanged in 1927 between the Director of Agriculture, Mauritius, and the Director of Agriculture, Ceylon, it was decided to introduce into Mauritius another species of cochineal insect, *Dactylopius tomentosus,* Lam., which was recorded by Hutson (24) to have done exceedingly well in the control of *Opuntia dilleni,* Haw., in Ceylon. Between March and August, 1927, three shipments of this insect were received from Ceylon, out of which only one gravid female survived. It was from this single individual that colonies were bred in the insectarium on *O. tuna* and distributed throughout the Island in 1928 (18:266). Fifty different centres of distribution were recorded in 1929 (19:5) and in one place more than 300 acres of infested land were under control (Pl. XV, figs. 2 and 3). In 1931, *D. tomentosus* had spread over nearly the whole Island (42:12) and large tracts of land were reported free from prickly pear. At the time of writing *O. tuna* has been almost completely eradicated from the Island by *D. tomentosus*. Moreover, it has been found that *D. tomentosus* could breed equally well on *O. monacantha* as on *O. tuna*.

This success can be quoted as a classical example of the control of a noxious plant by beneficial insects.

The biology of *D. tomentosus* was studied by d'Emmerez in 1927 (18:266-267).

It is worth recording that characteristic plant communities have succeeded *Opuntia tuna* in lands previously infested with this latter plant. For example, the community *Leucaena glauca/Opuntia tuna,* which thrived well before the introduction of *D. tomentosus,* has, in the first instance, been succeeded by *Leucaena glauca/Cordia interrupta* and this latter by *C. interrupta* only.

Icerya seychellarum, Westwood (Common White Mealybug).

I. seychellarum is one of the oldest known Coccids of Mauritius. Its distribution in the Island is wide, judging from its host range which is considerable; nearly all orchard and ornamental plants are attacked and damage is sometimes so severe as to cause the death of the infested plants. It is worth recording that *I. seychellarum* has not been found breeding on sugar-cane in the Island, though it has been found on that plant in other countries.

Several contact insecticides have been tried against this pest. Sulphomulsol (49:24), engine-oil emulsion (49:32), and an emulsion of diesel oil and clay (61:31, 40; 30:48) have been used with more or less success. In almost all cases the concentration at which the emulsions should be used was found to be harmful to the tender stems and young leaves of the infested plants.

Control by the local Coccinellid predators, *Rodolia chermesina,* Muls., and *Exochomus laeviusculus,* Wse., together with the use of banding grease, has given good results (50). The object of the banding grease is to prevent the black ant, *Technomyrmex detorquens,* Wlk., from reaching the mealybugs and, in that way, favours considerably the breeding of the Coccinellids. In spite of the presence of the above predators, *I. seychellarum* is not kept under control unless banding grease is applied.

Attempts to introduce the well-known predator, *Rodolia cardinalis,* Muls., from South Africa were made in 1915 by d'Emmerez de Charmoy (45:145) but he reported that this Coccinellid, though breeding on *I. seychellarum* in the laboratory, did not produce further generations when released in the field. Further importations of *R. cardinalis* from South Africa were made in 1937-38 (29:44; 30:48). It is interesting to note that at least three generations of this Coccinellid could be bred in the laboratory on *I. seychellarum,* but it was observed that in-breeding appeared to weaken the stock to such an extent that no further generations could be obtained. Of the individuals obtained from these three generations over 1,000 were released, but again no recovery has resulted.

The inability of *R. cardinalis* to breed successfully on *I. seychellarum* may be due to the fact that young larvae, which feed more readily on eggs than on adults of *Icerya* (1:168), may experience a lack of food when bred on *I. seychellarum* since the ovisac of this species is more or less closed as compared with that of *I. purchasi,* Mask.

Pseudococcus brevipes, Cockerell (Pineapple Mealybug).

P. brevipes was first reported as a major pest of pineapple plants in Mauritius as far back as the year 1933 (69:22; 47:28). The date of introduction of this mealybug is not certain but it probably came in consignments of pineapple suckers received from Hawaii, in or about the year 1931. The first sign of pineapple wilt was noticed in 1932 in the northern part of the Island (69:22). This wilt was definitely proved by Jepson and Wiehe to be due to *P. brevipes* (78:36; 30:45; 34:5, 7). Immediate steps were taken to cope with the pest and, after a series of experiments, Jepson and Wiehe (34:8) recommended that pineapple plantations should be sprayed with a diesel-clay emulsion at a dilution of 1 per cent. oil, using a high pressure sprayer, of the Vermorel Ondine Type. These authors further recommended that four to five applications of the diluted diesel-clay emulsion should be made at six-weekly intervals, in order to eliminate gradually the mealybug population (34:10-11).

Natural enemies of *P. brevipes* are represented in Mauritius by two predacious insects, the Coccinellid, *Scymnus mauritiusi,* Korschf., and the Drosophilid, *Gitonides perspicax,* Knab. The effect of these two predators is in general negligible. Attempts were made in 1938-39 to introduce the cosmopolitan Coccinellid, *Cryptolaemus montrouzieri,* Muls., from South Africa (30:45; 31:19). Three shipments of this predator were received and 1,050 individuals in the larval and adult stages were introduced; of these only 282 were alive. It was subsequently bred in the laboratory on several species of mealybugs, including *P. brevipes* which was readily attacked, but principally on *Phenacoccus insolitus,* Green. A total of 1,940 insects, mostly in the adult stage, were liberated, in 1939-40, in colonies of 50-100 individuals, in 19 localities. In one locality only, Barkly Experimental

Station, where several species of *Pseudococcus* could be easily found, 480 *C. montrouzieri* were liberated at varying intervals in colonies ranging from 30 to 200 individuals. In spite of these efforts, it has not been recovered either in pineapple fields infested with *P. brevipes* or on plants infested with other Pseudococcids, including *Phenacoccus insolitus*. The introduction of *C. montrouzieri* into Mauritius must therefore be considered a failure.

The actual status of *P. brevipes* can be summarised as follows.

It is generally found in nearly all pineapple plantations in such numbers as to cause summer and winter wilts of the plants. Early treatment of infested plants (December to March) with diesel-clay emulsion generally helps the growth and enables a crop to be reaped. The cost of late treatment is then so high as not to be a paying concern to small pineapple planters.

Another species of mealybug closely allied to *P. brevipes* occurs on pineapple in Mauritius, and has recently been described by Mamet under the name of *P. pseudobrevipes* (36:58). The rôle of this species has not been studied.

Fruit-flies.

The first record of a fruit-fly of economic importance in Mauritius is due to Coquillett, who described *Dacus sigmoides* in 1901 (*cf.* 2:100).

In 1913, d'Emmerez de Charmoy (10:12) recorded "*Ceratitis capitata*" and "*Dacus ferruginea*" as causing damage to fruits. These species were subsequently identified as *Ceratitis catoirei*, Guér., and *Dacus sigmoides*, Coq. D'Emmerez de Charmoy recorded in 1914 (11:19) another species on cucurbits under the name of *Dacus* sp. This species was described as new by Bezzi in 1917 as *Tridacus d'emmerezi* (3:63). The only change between 1917 and 1941 was that *D. sigmoides* became first *D. brevistylus*, Bezzi, and then *D. ciliatus*, Lw., under which name it is now known.

As a result of a survey made in 1942, other species of Trypetids were collected and identified by H. K. Munro. The following brings up to date the list of fruit-flies recorded from Mauritius (60:16):—

Strumeta zonata, Saund. (=*Chaetodacus zonatus*, Saund.), *Strumeta cucurbitae*, Coq. (=*Dacus cucurbitae*, Coq.), *Dacus* (*Didacus*) *ciliatus*, Lw., *D. d'emmerezi*, Bez., *Ceratitis capitata*, Wied., and *C. catoirei*, Guér. This brings the total number in the Island to six, of which two (*D. d'emmerezi* and *C. catoirei*) are indigenous, two African (*D. ciliatus* and *C. capitata*) and two Oriental (*S. zonata* and *S. cucurbitae*).

The two species of *Dacus* and *S. cucurbitae* have been found on cucurbitaceous fruits only: bottle gourd (*Lagenaria vulgaris*), carilla fruit (*Momordica charantia*), cucumber (*Cucumis sativus*), cho-cho (*Sechium edule*), melon (*Cucumis melo*), "pipengaille" (*Luffa acutangula*), pumpkin (*Cucurbita maxima*), snake gourd (*Trisocanthes anguina*), squash (*Cucurbita melo-pepo*) and water-melon (*Cucumis vulgaris*). *S. zonata* was collected on Badamia nuts (*Terminalia catappa*). *Ceratitis catoirei* has been reared from various fruits: chillies (*Capsicum annuum*), Chinese guava (*Psidium cattleianum*), various *Citrus* fruits, guava (*Psidium guajava*), jamalac (*Eugenia aquea*), jamrosa (*Eugenia jambos*), loquat (*Eriobotrya japonica*), mango (*Mangifera indica*), pawpaw (*Carica papaya*), peach (*Prunus persicae*), pomegranate (*Punica granatum*), whilst *C. capitata* has been bred from peach fruits (*Prunus persicae*) only.

The life-cycles of *D. ciliatus* and *D. d'emmerezi* have been worked out and found to vary from 18 days in summer to 25 days in winter (47:27). Experiments with various attractants (scents) and poison baits have been tried, both in the laboratory and in the field, without great success (43:48; 47:27).

Attempts to introduce a pupal parasite, the Braconid, *Opius phaeostigma*, Wlkn., from South Africa were made in 1933-35 (47:27; 48:26; 53:32). This species successfully parasitised both *D. ciliatus* and *D. d'emmerezi* in captivity but, owing to the small numbers received, it could not be colonised in the Island (53:32).

In 1939, two species of Chalcidoids, *Dirhinus auratus*, Ashm., and *Spalangia* sp., were introduced from Ceylon where they were reported to parasitise fruit-flies (31:19). Both species were imported as host pupae, and from the 1,200 *Dirhinus* and 800 *Spalangia* shipped, only 200 and 80 individuals, respectively, were received alive. Nearly all the *Spalangia* were released. Laboratory breeding of *Dirhinus* was carried out on the local fruit-flies, especially *Dacus*, and 568 individuals were released during the years 1939 and 1490. No recovery of these Ceylonese parasites has yet been recorded.

The factor limiting the increased cultivation of cucurbitaceous crops in Mauritius is mainly the fruit-fly problem. The importation of pupal parasites has not given the results that were anticipated, and the use of chemical means of control has not been encouraging, except that the Mally fruit-fly bait (for *Dacus* flies) may give fairly good results when its application is made at the correct time, *i.e.*, as soon as the plants begin to flower.

Stomoxys nigra, Macquart.

This is the most important blood-sucking fly in Mauritius and has been recorded for many years, being extremely common in 1901, when the first epidemic of surra (caused by *Trypanosoma evansi*, Steel 1885) created much havoc among the draught animals of the Colony. The gravity of the epidemic may be gauged by the fact that from July to October, 1902, 3,563 draught animals (1,882 equines and 1,681 cattle) died from surra (40:211; 41:5). The rôle of *S. nigra* in the transmission of the disease was at that time unknown. In 1905, Manders (39:625) reported that the disease in Mauritius was believed to be disseminated by *S. nigra*, which he erroneously referred to as *S. geniculatus*. In 1907, Edington and Coutts (20) recorded that trypanosomes of surra were found in stomachs of specimens of *S. nigra* in Mauritius and added that Daruty de Grandpré had succeeded in infecting a healthy dog with the trypanosome. Systematic experiments to prove that *S. nigra* was the vector of *Trypanosoma evansi* in Mauritius were successfully carried out by Moutia in 1928 (40:214-215; 41:10-12). These experiments proved conclusively (i) that *S. nigra* can convey *T. evansi* mechanically, *i.e.*. without passing through a developmental cycle, from an infected to a healthy animal; (ii) that the trypanosomes are still active at 25-27° C. in the proboscis of this fly from one to ten minutes after an infected meal and (iii) that it is during that period (not more than 10 minutes after the infected meal) that transmission of the trypanosome from an infected to a healthy animal can be successfully effected.

The complete life-cycle of *S. nigra* has been worked out by Moutia (40:213; 41:9) and found to vary from 27 to 35 days at temperatures ranging from 25 to 30° C. Moutia also noticed that pupation may occur at a depth of 6-8 ins. in the soil according to the soil humidity (56). The same author (56), working on this fly in 1937, found that the oviposition media of *S. nigra* in Mauritius may consist, in the open, of cut or dried grass adequately moistened with water and at an early stage of fermentation, or of cattle droppings of sufficiently good texture and moisture content for fermentation, or of moistened grass soiled with cow droppings or urine. In other words, moisture and slight fermentation are of importance for oviposition. It has, however, been noticed that *S. nigra* is very seldom found breeding in ordinary farmyard manure; it is probable that the development of the larvae in farmyard manure is stopped, even when oviposition has occurred, by the high temperature of the manure heaps which, in some cases, may reach 40°C. The texture of farmyard manure, *i.e.*, the very wet conditions of the medium and the large amount of urine and water it contains during the fermentation process, may also be a handicap in the development of the fly.

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* This fly was described from Réunion Island by Macquart (1851, Mém. Soc. nat. Sci. Lille, Année 1850, p. 239, Tab. 22, fig. 5). In 1907, Picard described *S. lafonti*, sp. n., from Mauritius (1907, Bull. Soc. ent. France, p. 28); this species was made a synonym of *S. nigra*, Macq., in 1909 by Austen in his "African Blood-sucking Flies", p. 154 (note).

The high incidence of *Stomoxys* noticed each year at the beginning of summer can be explained as follows. No definite place exists where *Stomoxys* breeds " en masse " in Mauritius and no breeding places where this fly can be found in great numbers during its early stages have ever been found. During the winter season, August to September, pastures are generally almost dried yet this is the time when *S. nigra*, though rare in large numbers on animals, can be found in small numbers on animals in pastures. During this period a few showers generally occur and it may not, therefore, be impossible that dead or cut grass in pastures may become suitable for oviposition. A first generation of flies may soon bring other generations and, when the heavy rains start early in October-November, it is generally noticed that there is a large increase in the fly population. This argument is supported by the fact that early heavy rains are invariably followed by high incidence of *Stomoxys*. If the *Stomoxys* larvae are not found in the pastures, it is because they are extremely difficult to detect in the field. W. S. Patton (64:513) working in India on *S. calcitrans*, L., writes: " As the eggs are always laid singly, a few at a time, and are scattered in the larval foodstuff the larvae are, as a rule, difficult to find even in localities where the adults may be numerous ". Dr. Langeron (35:231), another well-known authority, writes as follows on *Stomoxys*: " Ces faits démontrent que les Stomoxes peuvent pondre au voisinage immédiat des lieux habités, dans les détritus végétaux peu ou pas fermentés et par conséquent à température peu élevée. Les larves sont toujours enfoncées très profondément . . .". The above facts may explain why *Stomoxys* larvae are not commonly found in pastures in Mauritius, though they may actually breed there. It is therefore concluded that there is no natural mass emergence of *Stomoxys nigra*, and that the adult flies must emerge, one by one, from the numerous pupae scattered all over the large areas under pasture; when such individuals congregate in search of food they give the impression that *Stomoxys* breeds " en masse ".

A second species of *Stomoxys* (*calcitrans*, L.) has recently been recorded by Vinson (77:127) who found it, in fairly large numbers, in the centre of the Island. Since that date, 1942, it has not been reported spreading to other localities. It is too early to report on the rôle of this blood-sucking fly, but it was probably introduced in 1937, from Java or South Africa.

Amongst the control measures adopted against these flies are the use of the Bourgault Fly-trap and the Harris Fly-trap. It is not within the scope of this paper to discuss the value of these traps.

Only one Chalcidoid parasite, probably *Spalangia* sp., has been reared from pupae of *S. nigra* in Mauritius. Its occurrence has not been fully studied, but, its influence appears to be insignificant. It was hoped to introduce the Histerid beetle, *Hister chinensis*, Quensel, whose larvae are predacious on house-fly larvae in Java (28:84), but this had to be postponed on account of the war.

Solenopsis geminata, Fabricius (Red Ant).

In 1921, d'Emmerez de Charmoy (14:16) recorded that the Red Ant had existed in Mauritius for about 20 years and, at that time, it was quite common on the coastal belt and relatively rare in the higher localities. The ant has since spread all over the Island and is fairly common in the uplands. Apart from its devastating effects on seed beds and seedlings, it occurs widely in pineapple plantations infested with *Pseudococcus brevipes,* Ckll.

No parasites and predators have been reported on *Solenopsis* in Mauritius. Apart from the treatment of nests with powerful insecticides, such as Cyanogas, the use of diesel-clay emulsion is recommended (61:25; 30:49). Thallium sulphate, as advocated by Travis (73:56) has been tried without success.

Technomyrmex detorquens, Walker (Black Ant).

Technomyrmex detorquens (=*T. albipes,* Smith) was not recorded in 1921 by d'Emmerez de Charmoy (14:15-18) amongst the accidentally introduced insect pests of Mauritius. A few years later, this ant was noticed in many localities and was common as a household pest. At the present time, *T. detorquens* is abundant throughout the country where it is either found in houses or fostering mealybugs on plants. Its rôle as a limiting factor in the development of predators of mealybugs, especially Coccinellids, has already been mentioned (cf. *Icerya seychellarum,* p. 463). Experiments have shown that Barber's poisoned bait is very effective (49:34) against this ubiquitous pest.

Termites.

As a result of an intensive survey carried out in 1933-1935 by Moutia (52), the following termites were recorded in Mauritius:

Termes mauricianus, Ramb.
Nasutitermes voeltzkowi, Wasm., and var. *minor,* Wasm.
Kalotermes (*Cryptotermes*) *pallidus,* Ramb.
Kalotermes (*Cryptotermes*) *havilandi,* Sjöst., and subsp. *parasitica,* Wasm.
Kalotermes (*Neotermes*) *hova,* Wasm., var. *mauritiana,* Sjöst.
Heterotermes philippinensis, Light.
Prorhinotermes canalifrons, Sjöst.
Coptotermes havilandi, Holmg.
Kalotermes (*Procryptotermes*) sp. n.
Kalotermes (*Cryptotermes*) sp. n.

The systematics of the above species have been discussed by the same author (52:5-6, 29) and the status and bionomics of most of them studied (52:9-24). The species responsible for the most important damage to wooden buildings are *K. havilandi, H. philippinensis, K. pallidus, C. havilandi* and *N. voeltzkowi.* No standard method of protection against termites is in use in the Island. Removal of runways and subsequent treatment of affected wood with creoline or some form of a coal-tar and creosote preparation are methods that have been used for some time. The use of pre-impregnated timber has been very limited, but an intensive use of several proprietary wood preservatives has been tried with little or no success. Experiments with hot preservatives, consisting chiefly of crude oil from local wood tar and heavy diesel oil, have recently been devised by Jepson in Mauritius. These tests are still in progress, but it can be stated that pieces of treated timber have remained unattacked by *N. voeltzkowi* for over 24 months, in spite of the heavy infestation prevailing in the test centre where the impregnated timber is under observation. It is worth recording that no indigenous timber is known to be markedly resistant to termite attacks. Among other methods of control in Mauritius, the blowing of various chemicals in dust form into nests and galleries has given good results. Arsenious oxide, according to the following formula which was devised by Mamet and Durocher (38:59) in 1941, has proved the most satisfactory.

Arsenious oxide	40 per cent.
Potassium antimonate	5 per cent.
Borax	2 per cent.
Jeweller's Rouge	53 per cent.

These chemicals, which should be dry, are powdered so as to pass through a 100 mm. mesh sieve, mixed and applied into the nests and galleries. The control of *N. voeltzkowi* has proved to be 100 per cent. effective after one application but, with species of *Kalotermes, Coptotermes* and *Heterotermes,* several applications of the dust should be made to secure the complete destruction of their colonies.

In 1931, Professor H. Kirby, while visiting Mauritius, collected all the known species of termites of the Island with a view to studying their protozoan fauna, but the results of this investigation are not yet known.

It is very difficult to assess the losses caused by termites in Mauritius but all wooden buildings need repairs at least 15 years after their construction as the result of termite attacks.

Summary.

The practical results achieved in the past twenty-five years' work on the major insect pest problems of Mauritius are discussed.

The major insect pests studied are the white grubs of sugar-cane, *Clemora smithi* (=*Phytalus smithi*) and *Oryctes tarandus*; the sugar-cane moth borers, *Proceras sacchariphagus, Sesamia vuteria,* and *Argyroploce schistaceana*; the coconut scale-insect, *Aspidiotus destructor*; the pineapple mealybug, *Pseudococcus brevipes*; the cochineal insects of the prickly pears, *Dactylopius tomentosus* and *D. indicus*; fruit-flies; the biting flies, *Stomoxys nigra* and *S. calcitrans*; the red ant, *Solenopsis geminata*; the black ant, *Technomyrmex detorquens*; and termites.

The actual status of these pests is given in detail. *Clemora smithi,* which was first recorded in 1911, is still a major pest of sugar-cane in spite of the 43 species of parasites and 2 species of predators introduced to check it. *Oryctes tarandus* very seldom causes severe damage now to sugar-cane plantations. It is a sporadic pest, and has been definitely held in check since the Scoliid wasp, *Scolia oryctophaga,* was introduced from Madagascar in 1917.

The status of the three moth borers of sugar-cane and that of their parasites is fully dealt with. Of the five species of parasites introduced from Ceylon and Madagascar in 1938-40 to control *Proceras sacchariphagus,* only one has so far been recovered and its beneficial effect is very limited. An account is given of experiments on the mass liberation of the egg parasites, *Trichogramma australicum* and *T. evanescens.* The results were in both cases deceptive. The spotted borer, *P. sacchariphagus,* is a major pest of sugar-cane in some localities and further introductions of parasites from other cane-growing countries are recommended.

The coconut scale, *Aspidiotus destructor,* which, since 1927, threatened all the coconut plantations of the Island, is now under control, owing to the introduction from Ceylon and Java, respectively, of the predacious Coccinellids, *Chilocorus nigritus* and *C. politus.* The bionomics of the various parasites and predators of this scale in Mauritius are fully described.

A historical review is given of the introduction of the cochineal insects of prickly pear, *Dactylopius indicus* and *D. tomentosus* in the Island. The completely successful eradication of *Opuntia tuna* and *O. monacantha,* by these two Coccids is given as a typical example of the biological control of noxious plants by insects.

The pineapple mealybug, *Pseudococcus brevipes*, which is responsible for wilting disease, is considered to be one of the factors limiting the development of the pineapple industry in Mauritius. Spraying with a diesel-clay emulsion, though checking this pest, is limited in its application. Further introductions of parasites and predators are desirable.

The common white mealybug, *Icerya seychellarum*, is still a major pest of orchards and ornamental plants in spite of the presence of the local Coccinellid predators, *Rodolia chermesina* and *Exochomus laeviusculus*. Practical control can be achieved by the use of banding grease coupled with the attacks of predators. No local parasite has been recorded in Mauritius.

Six species of Trypetids are recorded. Of these, the flies attacking cucurbitaceous fruits are the most harmful. Experiments with numerous attractants for fruit-flies are mentioned. The only bait showing any success in the control of the *Dacus* flies is the Mally fruit-fly bait. Parasites have been imported from South Africa and Ceylon without success. Further attempts should be made.

The bionomics and breeding places of the blood-sucking fly, *Stomoxys nigra*, are described.

The Red Ant, *Solenopsis geminata*, is a major pest of seedlings in Mauritius. It is now destroyed by the use of a diesel-clay emulsion. Baits containing thallium sulphate have been tried without success.

The rôle of the Black Ant, *Technomyrmex detorquens*, in preventing development of the Coccinellid predators on *Icerya seychellarum* is emphasised. Barber's poisoned bait has been found very useful against this household pest.

A review of the species of termites found in Mauritius as well as the various means of control used against them are given. An insecticidal powder containing arsenious oxide has given the best results.

During the last 25-30 years, 64 species of parasites and predators have been imported for the biological control of eight species of insects of major economic importance and of two species of noxious plants.

The results achieved indicate that the introduction of parasites and predators in insular countries like Mauritius should be carried out *only* after a thorough investigation of the various ecological, biotic and climatic factors existing between the country of exportation and the country of importation.

The rôle of cyclonic disturbance in the fluctuation of the parasite population is mentioned. Scoliid parasites, for instance, are generally scarce after violently disturbed weather and may sometimes remain so for two or three years after the disturbance.

References.

1. Balachowsky, A. (1932). Etude biologique des Coccides du bassin occidental de la Mediterranée.—Encycl. Ent. (A) **15**, 214+lxxi pp., 46 figs., 14 maps, 7 pls.

2. Bezzi, M. (1915). On the Ethiopian fruit flies of the genus *Dacus*.—Bull. ent. Res., **6**, pp. 85-101, 14 figs.

3. ——. (1917). New Ethiopian fruit flies of the genus *Dacus*.—Bull. ent. Res., **8**, pp. 63-71, 6 figs.

4. Bojer, W. (1856). Report of the Committee on the "Cane Borer", 4 pls.

5. BONAME, P. (1896). Rapport annuel de la Station Agronomique pour 1895, 81 pp.

6. ——. (1898). Rapport annuel de la Station Agronomique pour 1897, 91 pp.

7. COOMBES, A. N. (1937). The evolution of sugar cane culture in Mauritius, p. 177.

8. CRAIG, N. (1934). Some properties of the sugar cane soils of Mauritius.—Bull. Sugar cane Res. Sta. Mauritius, no. 4, 25 pp., 1 map.

9. D'EMMEREZ DE CHARMOY, D. (1912). Rapport sur le *Phytalus smithi* Arrow, 34 pp.

10. ——. (1914). Rep. Dep. Agric. Mauritius, 1913, pp. 10-12.

11. ——. (1915). Rep. Dep. Agric. Mauritius, 1914, pp. 17-20.

12. ——. (1916). Moth borers affecting sugar cane in Mauritius.—Bull. Dep. Agric. Mauritius, Sci. Ser., no. 5, 27 pp.

13. ——. (1917). Notes relative to the importation of *Tiphia parallela,* Smith, from Barbados to Mauritius for the control of *Phytalus smithi,* Arrow.—Bull. ent. Res., **8,** pp. 93-102, 1 map.

14. ——. (1921). Notes on insects accidentally introduced into the island of Mauritius.—Bull. Dep. Agric. Mauritius, Sci. Ser., no. 8, 20 pp.

15. ——. (1923). An attempt to introduce Scoliid wasps from Madagascar to Mauritius.—Bull. ent. Res., **13,** pp. 245-254, 4 pls.

16. ——. (1927). Report on the operations for the control of *Phytalus smithi,* Arrow, during season 1926-27, 13 pp.

17. ——. (1927). La cochenille du Cocotier, *Aspidiotus destructor,* Signoret.—Leafl. Dep. Agric. Mauritius, no. 24, 3 pp.

18. ——. (1928). *Opuntia tuna.* Rev. agric. Maurice, no. 42, pp. 264-267.

19. ——. (1930). Rep. Dep. Agric. Mauritius, 1929, pp. 4-6.

20. EDINGTON, A. & COUTTS, J. M. (1907). A note on the recent epidemic of Trypanosomiasis at Mauritius.—Lancet, October 5th, 1907.

21. EDWARDS, W. H. (1928). Experiments with insecticides against *Phytalus* grubs. *In* Report on the operations for the control of *Phytalus smithi,* Arrow, during the season 1927-1928, pp. 9-10.

22. ——. (1928). Le *Phytalus Smithi.* Leafl. Dep. Agric. Mauritius, no. 28, 7 pp.

23. EVANS, H. (1941). 11th Rep. Sugar Cane Res. Sta. Mauritius, 1940, part III, Research, Botany, pp. 17-29.

24. HUTSON, J. C. (1926). Prickly Pear and Cochineal insects.—Trop. Agriculturist, **67** (5), pp. 1-3, 2 pls.

25. ICERY, M. E. (1864). Mémoire sur le Pou à poche blanche, 8 pp., 6 pls., Mauritius.

26. JEPSON, W. F. (1936). Report on the search for parasites for *Phytalus Smithi,* Arrow, 66 pp., 7 maps, 3 app.

27. ——. (1936). A summary of the results of the *Phytalus* investigations 1933-36 with recommendations as to further lines of work, 19 pp.

28. ——. (1939). Progress in parasite investigation during 1938.—Rev. agric. Maurice, no. 105, pp. 82-84.

29. ——. (1939). Rep. Dep. Agric. Mauritius, 1937, pp. 41-46.

30. ——. (1939). *Op. cit.,* 1938, pp. 40-51.

31. ——. (1941). *Op. cit.,* 1939, pp. 16-19.

32. JEPSON, W. F. & MOUTIA, L. A. (1939). The progress of applied entomology in Mauritius during the years 1933-38 with reference to insects of the sugar-cane.—Proc. int. Soc. Sugar-Cane Tech., **6**, pp. 377-383.

33. —— & REGNARD, L. P. (1931). The parasites of Melolonthids at Nossi Bé Madagascar.—Int. Sugar J., **38**, pp. 414-415.

34. —— & WIEHE, P. O. (1939). Pineapple wilt in Mauritius.—Bull. Dep. Agric. Mauritius, Gen. Ser., no. 47, 15 pp., 2 app.

35. LANGERON, M. (1910). Remarques sur la ponte du *Stomoxys calcitrans* et l'élevage des larves de Muscides.—C.R. Soc. Biol., 1910, p. 231.

36. MAMET, R. (1941). A new mealybug attacking pineapple plants in Mauritius. —Bull. ent. Res., **32**, pp. 57-59.

37. ——. (1943). A revised list of the Coccoidea of the Islands of the Western Indian Ocean, south of the equator.—Mauritius Inst. Bull., **2**, pp. 137-170, 1 map.

38. —— & DUROCHER-YVON, F. (1941). La lutte contre les termites à Maurice et l'application de l'arsenic pour combattre ces insectes.—Rev. agric. Maurice, no. 20, pp. 59-61.

39. MANDERS, N. (1905). Surra as it occurs in Mauritius.—J. roy. Army med. Cps., no. 5, pp. 623-626.

40. MOUTIA, L. A. (1928). Surra in Mauritius and its principal vector, *Stomoxys nigra*.—Bull. ent. Res., **19**, pp. 211-216.

41. ——. (1928). Le surra à Maurice et son principal vecteur, *Stomoxys nigra*. —Bull. Dep. Agric. Mauritius, Sci. Ser., no. 12, 12 pp.

42. ——. (1932). Rep. Dep. Agric. Mauritius, 1931, pp. 9-12.

43. ——. (1933). *Op. cit.*, 1932, pp. 43-51, 2 app., 2 figs.

44. ——. (1933). Report on missions sent to Madagascar in search of parasites in connection with the *Phytalus* problem in Mauritius, 6 pp., 5 app., 1 map, 12 photos.

45. ——. (1933). Le statut actuel des insectes nuisibles et des insectes utiles à l'agriculture de l'Ile Maurice.—Rev. agric. Maurice, no. 70, pp. 144-148.

46. ——. (1934). The sugar-cane moth borers in Mauritius.—Bull. ent. Res., **25**, pp. 33-41, 1 pl.

47. ——. (1934). Rep. Dep. Agric. Mauritius, 1933, pp. 25-29.

48. ——. (1935). *Op. cit.*, 1934, pp. 25-26.

49. ——. (1935). The commoner insect pests of orchards, vegetable and flower gardens in Mauritius.—Bull. Dep. Agric. Mauritius, Gen. Ser., no. 44, 39 pp.

50. ——. (1935). Notes sur un nouveau moyen de lutte contre le pou blanc ou *Icerya seychellarum*, West.—Leafl. Dep. Agric. Mauritius, no. 39, 4 pp.

51. ——. (1936). The sugar-cane white grub. *Lachnosterna* (*Phytalus*) *smithi*, Arrow, in Mauritius.—Proc. int. Soc. Sugar-cane Tech., **5**, pp. 436-445.

52. ——. (1936). Termites in Mauritius.—Bull. Dep. Agric. Mauritius, Sci. Ser., no. 21, 30 pp., 3 pls., 18 photos.

53. ——. (1936). Rep. Dep. Agric. Mauritius, 1935, pp. 30-33.

54. ——. (1937). *Op. cit.*, 1936, pp. 37-39.

55. ——. (1937). Notes sur l'introduction à Maurice de nouveaux prédateurs de la Cochenille du cocotier, *Aspidiotus destructor*, Signoret.—Rev. agric. Maurice, no. 95, pp. 164-165.

56. Moutia, L. A. (1937). Unpublished report on breeding places of *Stomoxys nigra* in Mauritius.

57. ——. (1940). The search for parasites of white grubs (Melolonthids) in Zanzibar, Algeria, Morocco and France.—Bull. ent. Res., **31**, pp. 193-208, 4 pls., 5 figs.

58. ——. (1941). Rep. Dep. Agric. Mauritius, 1940, pp. 14-16.

59. ——. (1942). *Op. cit.*, 1941, pp. 14-21.

60. ——. (1943). *Op. cit.*, 1942, pp. 12-16.

61. ——. (1943). Commoner insect pests of orchards, foodcrops, vegetable and flower gardens in Mauritius.—Bull. Dep. Agric. Mauritius, Gen. Ser., no. 49, 49 pp.

62. ——. (1944). The sugar-cane scale, *Aulacaspis tegalensis*, Zehnt.—Bull. ent. Res., **35**, pp. 69-77, 2 figs., 1 pl.

63. ——. (1944). Rep. Dep. Agric. Mauritius, 1943, pp. 12-15.

64. Patton, W. S. (1933). Studies on the higher Diptera of medical and veterinary importance.—Ann. trop. Med. Parasit., **27**, p. 513.

65. Regnard, L. P. (1937-40). Unpublished reports.

66. Roberts, H. (1911). Les moutoucs.—Bull. agric. Maurice, 1911, p. 452.

67. ——. (1911). Les borers et les moutoucs.—Bull. agric. Maurice, 1911, p. 512.

68. Saulnier, J. M. (1916). La lutte contre les sauterelles dans divers pays.—Inst. int. Agric., Rome, xvi + 187 pp.

69. Shepherd, E. F. S. (1934). Rep. Dep. Agric. Mauritius, 1933, pp. 21-23.

70. Sornay, P. de. (1939). Le martin.—Rev. agric. Maurice, no. 104, pp. 52-57.

71. Tams, W. H. T. (1942). Note on the name of the sugar-cane borer in Mauritius.—Bull. ent. Res., **33**, pp. 67-68.

72. Taylor, T. H. C. (1935). The campaign against *Aspidiotus destructor* Sign. in Fiji.—Bull. ent. Res., **26**, pp. 1-100, 40 figs.

73. Travis, B. V. (1943). Further tests with thallium baits for control of the fire ant.—J. econ. Ent., **36**, pp. 56-58.

74. Vaughan, R. E. & Wiehe, P. O. (1937). Studies on the vegetation of Mauritius. I.—J. Ecol., **25**, pp. 289-343, 10 pls., 12 figs., 2 maps.

75. Vinson, J. (1941). Rectification d'une erreur courante relative à l'espèce de *Diatraea* s'attaquant à la canne à sucre à Maurice.—Rev. agric. Maurice, no. 20, pp. 148-153.

76. ——. (1942). Biological control of *Diatraea mauriciella*, Wlk., in Mauritius.—Bull. ent. Res., **33**, pp. 39-65, 7 figs.

77. ——. (1942). Une deuxième espèce de " mouche boeuf " à Maurice, *Stomoxys calcitrans* Linné.—Rev. agric. Maurice, **21**, pp. 127-128, 2 figs.

78. Wiehe, P. O. (1939). Rep. Dep. Agric. Mauritius, 1938, pp. 34-39.

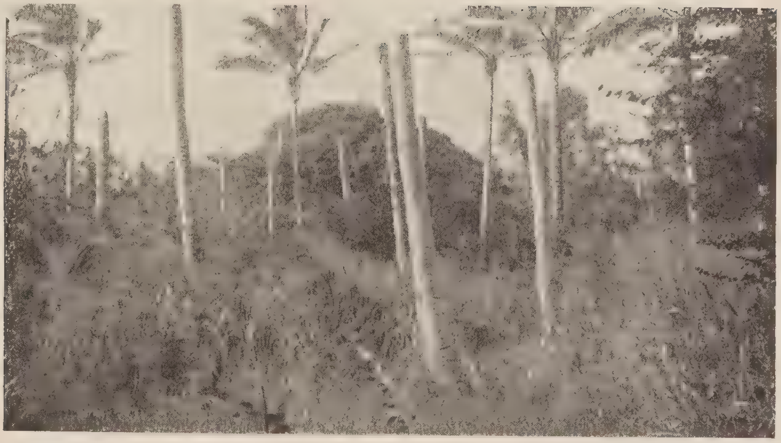
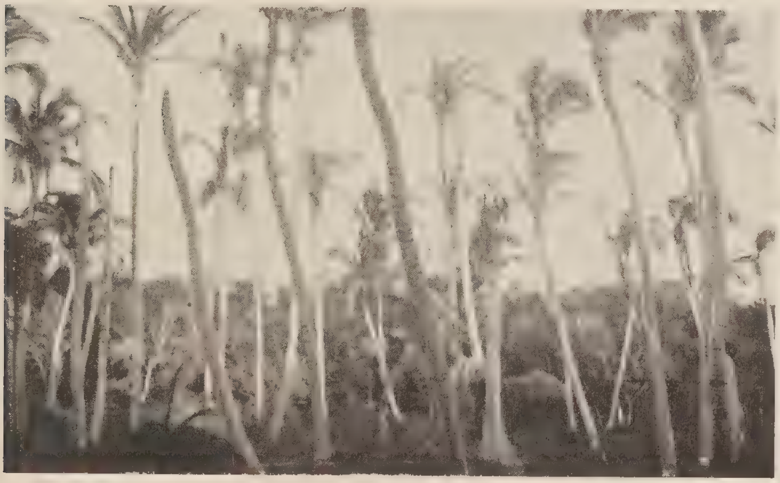


Fig. 1



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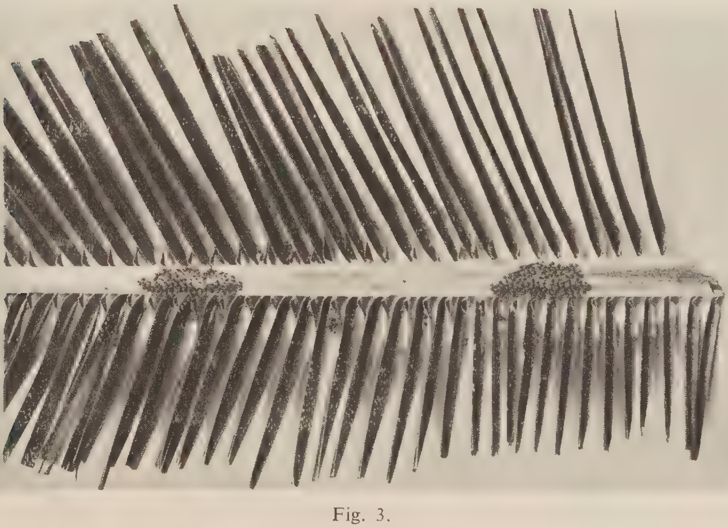


Fig. 3.

Figs. 1 & 2. Coconut plantations at Pointe aux Sables showing severe infestation of *Aspidiotus destructor*, Sign., in 1929.

Fig. 3. Infested leaf showing agglomeration of puparia of *Chilocorus politus*, Muls.

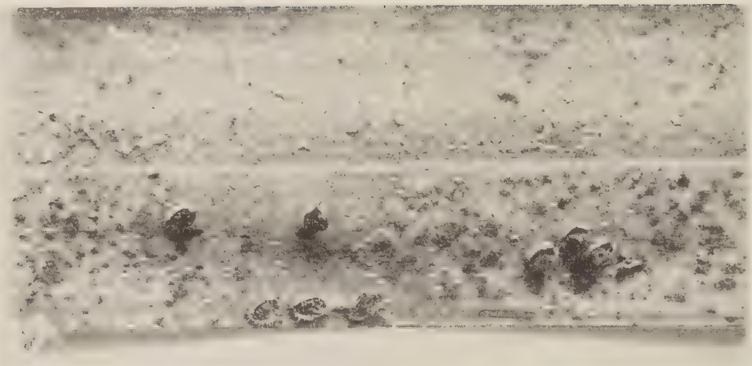
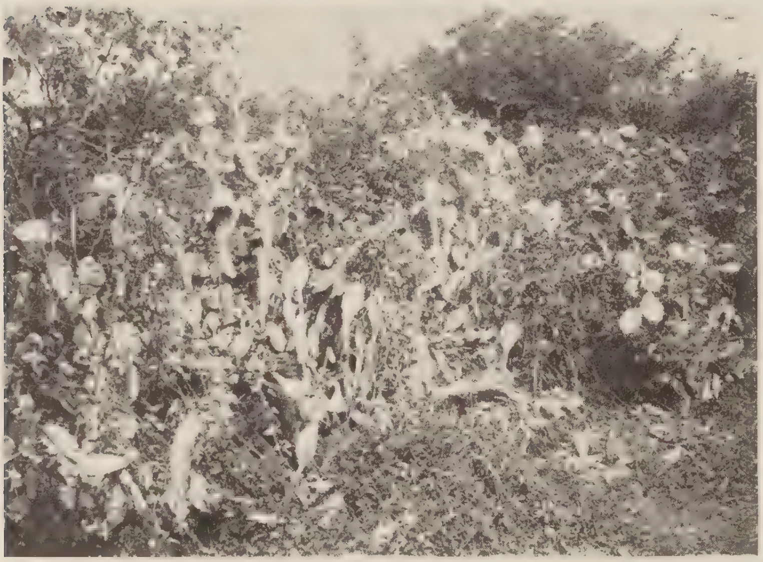


Fig. 1.



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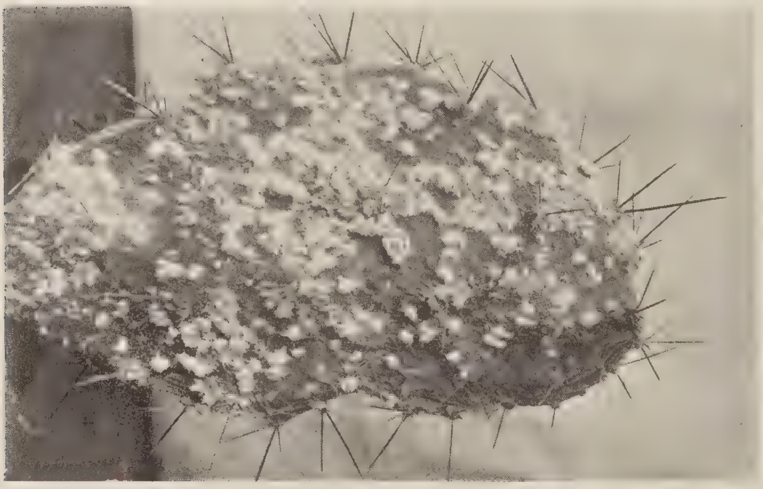

Fig. 3.

Fig. 1. Enlarged portion of a coconut leaflet showing the sweeping of the scale by *Chilocorus politus, Muls.* Note the pupal skins of the Coccinellid on the lower side.

Fig. 2. Natural infestation of *Opuntia tuna* by *Dactylopius tomentosus* (Lam.) in the Black River district in 1928.

Fig. 3. Portion of stem of *Opuntia tuna,* Mill.—attacked by *Dactylopius tomentosus* (Lam.)

THE MOSQUITOS OF THE KAIMOSI FOREST, KENYA COLONY, WITH SPECIAL REFERENCE TO YELLOW FEVER.

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(Plates XVI-XVII.)

Introduction.

Kenya Colony lies within the so-called endemic yellow fever belt of Africa and is in close contact with territories where the disease is common. Until 1942, the infection was apparently absent from the Colony; then in May that year, a fatal case occurred at Kitale (E. Afr. med. J., **19**, 1942, p. 105) on the slopes of Mount Elgon. The following year one of us reported another case at Kisumu. This case had become infected in the Langata Forest near Nairobi, and subsequent investigation showed that the forest was a mild focus of the disease.*

It is now well recognised that the root of the yellow fever problem lies in the jungle form of the disease and that most, if not all, of the urban and rural epidemics are off-shoots of this form. Soper (1938) refers to the way in which the jungle infection has come to dominate the epidemiological picture in Brazil and stresses the accidental nature of the infection in man, who is not an essential part of the jungle cycle. The isolation of the virus by Mahaffy *et al.* (1942) from a case living in a jungle area in Uganda and the alarming epidemic of the disease in the Nuba Mountains in 1940 as reported by Kirk (1943) indicate the reality of the problem in this part of Africa.

It is thus an important feature in the protection of a territory against yellow fever to ascertain if its forests are already infected or if the conditions within them are suitable for the development of the disease. The present investigation was made in order to determine these points in regard to a forest which lies not far from Kitale where the first recognised case in Kenya occurred and which is on the traffic route from the neighbouring territory of Uganda. Systematic work was begun in November, 1942, and was continued until October, 1944.

Little earlier work in Kenya has been done on the subject, though one of us surveyed the forested areas near Kitale in connection with the case that arose there and obtained adults of the following species of mosquitos:—

Aëdes (*Finlaya*) *ingrami*, Edw.
Aëdes (*Stegomyia*) *bambusae*, Edw.
Aëdes (*Aëdimorphus*) *dentatus*, Theo.
Aëdes (*Aëdimorphus*) *phyllolabis*, Edw.
Aëdes (*Aëdimorphus*) *quasiunivittatus*, Theo.
Aëdes (*Aëdimorphus*) *cumminsi*, Theo.
Aëdes (*Aëdimorphus*) *tarsalis*, Newst.
Aëdes (*Banksinella*) *circumluteolus*, Theo.
Eretmapodites sp. indet.
Anopheles (*Anopheles*) *implexus*, Theo.

More than 90 per cent. of over 1,000 adults caught in this survey belonged to the *Aëdimorphus* group. Weekly larval surveys for three years in Kitale itself revealed an *Aëdes aegypti* index of less than one per cent. and the presence of *A.* (*Stegomyia*) *africanus*, Theo., on 22 occasions.

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* The diagnosis was made on pathological and immunological evidence by the Yellow Fever Research Institute, Entebbe.

Locality and Inhabitants.

The Kaimosi forest occupies an area of about fifty square miles in the Nyanza Province of Kenya Colony and lies just north of the Equator at an altitude of 5,500 feet. It is approximately twelve miles long and five miles wide at most places. On the east, it is protected by the Nandi Escarpment, rising more than a thousand feet above the forest; to the north it is brokenly connected by small patches of forest with the extensive forests of Mount Elgon (14,140 feet).

The forest itself contains few inhabitants. Timber and mining companies and the Forest Department, however, employ some hundreds of African labourers who live within its boundaries, and the inhabitants of the heavily populated native reserves on its perimeter enter the forest freely for hunting and for collecting fuel, water and honey.

Kaimosi forest is classified by Battiscombe (1936) as belonging to the category of semi-tropical rain forests. Much of it is of a very considerable density; the trees grow to a height of eighty or ninety feet or more and form a complete canopy in most parts. The undergrowth is heavy and consists very largely of innumerable dracaenas. Large glades interrupt its continuity and on the south-east side, the fringe of the forest merges into coffee farms belonging to European settlers. The Yala River with numerous tributaries flows through the southern portion and the Sioko River through the northern. Both of these rivers flow into Lake Victoria and for much of their course are fast flowing streams about twenty to thirty yards in width.

The commonest trees are shown in the following list:—*Casearia battiscombei,* Fries., *Bridelia micrantha,* Baill., *Albizzia gummifera,* C.A. Sm., *Antiaris* sp., *Trema guineensis,* Ficalho, *Croton megalocarpus,* Hutch., *Funtumia latifolia,* Stapf, *Maba abyssinica,* Hiern., *Bosquiea phoberos,* Baill., *Craibia elliottii,* Dunn, and *Celtis* spp.

Scattered through the forest there are species of trees which are normally regarded as belonging to the " western " type of flora, but which appear here as their furthest extension eastwards. They include *Maesopsis eminii,* Engl.

Rainfall figures for the last nine years have been as follows:—1936 74 ins., 1937 84 ins., 1938 74 ins., 1939 62 ins., 1940 89 ins., 1941 81 ins., 1942 72 ins., 1943 60 ins., and 1944 73 ins.

Although there is a certain degree of seasonal distribution into " long " and " short " rains, there was no month quite without rain even in the exceptionally dry years of our investigation. The following monthly figures illustrate this:—

TABLE I.

Rainfall in Inches—Kaimosi Forest.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1943 ...	0·8	3·4	2·3	9·6	8·6	7·1	6·6	6·2	6·5	8·2	0·6	0·4
1944 ...	1·5	2·4	4·1	7·1	13·5	6·3	5·3	10·1	6·9	5·6	5·3	4·8

Towards the end of the dry season of 1943, most of the undergrowth had shrivelled up, the earth was dry and hard and in spite of the evergreen nature of the trees, small fires broke out in many parts of the forest. Practically no water was left in the tree-holes, rock pools or plant axils and the rivers became reduced to little more than trickling streams with many of their tributaries quite dry. The normal condition of the forest is in complete contrast; even when all the vegetation is not dripping with moisture, the humidity is so high that everything is damp.

Thermo-hygrograph tracings for a few days in May, 1943—a wet month—taken on the forest edge are shown in fig. 1. It will be noticed that except for a few hours in the middle of the day the relative humidity is nearly 100 per cent. The temperature range is much as is shown in this figure though it may drop to as low as 13°C. and rises to 30°C.

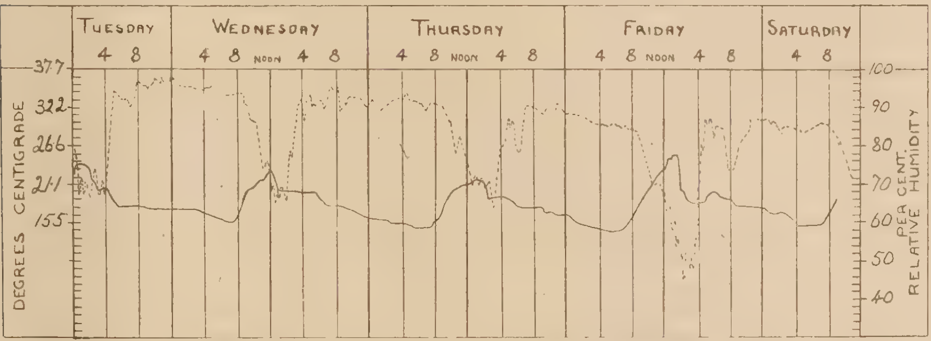

FIG. 1.—Thermo-hygrograph tracing—Kaimosi.
Unbroken line=temperature;
Dotted line=humidity.

Records obtained by the British East African Meteorological Service on a farm a mile outside the forest, in two successive years, showed a mean maximum temperature of 26°C. and a mean minimum of 16°C., giving a mean of 21°C. On the assumption that forest temperatures are two degrees lower (*vide infra*), the mean for the forest is 19°C., a figure which is on the low side for the *Aëdes aegypti* transmission of yellow fever which according to Davis (1932) ceases at 18°C. Jungle yellow fever, however, is known to occur when the *mean* temperature is as low as 18°C. with minima very much below those found in this forest. In a series of readings, there was little difference observed between the temperature near tree-top level (but below the canopy) and on the ground. Immediately outside the forest, the shade temperatures were about 20°C. higher. The temperature of the water in tree-holes was as much as 6°C. lower than that of the air in the forest.

Monkeys are plentiful and perhaps number as many as a hundred to the square mile. Species represented include the baboon (*Papio doguera furax*, Elliot), colobus (*Colobus polykomos matschiei*, Neum.), blue monkey (*Cercopithecus mitis kibonotensis*, Lönnberg), and the red tails (*Cercopithecus nictitans schmidti*, Matschie). The last two species have heavy blood infections of a *Plasmodium* (unidentified), but exhibiting circular macro- and microgametocytes with no enlargement or stippling of the red blood cell. Bush-buck, pig and leopard occur. The following typically West African species are found in Kaimosi in addition to a number of tree frogs and lizards:—Potto—*Perodicticus potto ibeanus*, Thomas; spring-tailed squirrel—*Anomalurus jacksoni*, de Winton; aquatic porcupine—*Atherurus turneri*, St. Leger and gaboon viper—*Bitis gabonica* (D. & B.). The fruit bat—*Epomophorus labiatus*, Dobson—at certain seasons is found in large numbers. Its blood contains a malarial parasite resembling *Plasmodium murinum*.

The natives (Bantu in origin) living on the fringes of the forest suffer principally from two diseases—malaria and onchocerciasis. A survey of 69 children revealed a malaria parasite rate of 46 per cent. made up as follows:—

Age, 0-3 years ...	Crescents 7 per cent.
Age, 4-9 years ...	*P. falciparum* 30 per cent., crescents 10 per cent. *P. malariae* 10 per cent.
Age, 10-15 years ...	*P. falciparum* 54 per cent., crescents 21 per cent. *P. malariae* 8 per cent.

During the course of this survey, many of the children complained of an intense skin irritation. Skin snippings were examined and 13 children out of 20 showed the microfilaria of onchocerciasis. At the same time, we noticed the presence of large numbers of *Simulium neavei*, Roub. Subsequent observations revealed the presence of this insect throughout Kaimosi both on the ground and at tree-top level, and 25 per cent. were found to be infected with the parasite. Skin snippings of monkeys showed no microfilaria.

Methods employed in the routine Mosquito Investigations.

In order to establish a weekly routine, it was found necessary to confine regular work to a circumscribed area of the forest in the southern portion. A deserted farm house was conveniently situated here and provided quarters for a laboratory and camp. After several weeks of preliminary work, the following types of breeding-place were selected to enable us to obtain a general picture of the sylvan fauna.

Special Tree-holes.

Thirty trees with good holes were chosen and labelled with metal discs. They comprised:—*Craibia elliottii*, Dunn (14 trees); *Rawsonia usambarensis*, K. Schum. (5 trees); *Harpullia fosteri*, Sprague (2 trees); *Ficus* sp. (2 trees); *Teclea nobilis*, Delile; *Trema guineensis*, Ficalho; *Pygeum africanum*, Hr. f.; *Trichilia emetica*, Vahl; *Bosquiea phoberos*, Baill.; *Croton megalocarpus*, Hutch.; *Cordia holstii*, Gurke; and *Cordia ovalis*, R. Br.

Two of the above were fallen trees. The sizes of the rot holes varied from large basins nearly a foot in diameter and depth to small crevices a couple of inches deep. One of the fallen trees had a cavity seven feet long. The height from the ground varied from ground level (holes in buttresses) to as high as eighteen feet.

In spite of careful selection, certain of the tree-holes became unfavourable to breeding through various adventitious circumstances, *e.g.*, during the course of the investigation, some became cracked, resulting in the water drying up quickly, others were exposed by the slope of the tree above to the deposition of caterpillars which poisoned the water, whilst others again proved to be favourite drinking places of wild animals. The water in the holes was " topped up " twice a week from cans filled with river water and provided with cloth filters at the spout. They were examined once a week and fourth-stage larvae were removed for identification.

The addition of water to tree-holes (and to holes in granite boulders) vitiated to some extent observations on the seasonal incidence of mosquitos, and fluctuations in numbers as a rule were much more obvious in species breeding in places (*e.g.*, streams) which were not kept artificially filled.

General Tree-holes.

In order to survey a larger area of the forest than that covered by the thirty special trees, journeys were made once a week in all directions and trees were searched for breeding. A few additions to the list of species were thereby obtained, though the general fauna was similar.

Containers at Regular Heights.

The isolation (Rockfeller Annual Report, 1941) of the virus of yellow fever in *Haemagogus capricornii*, Lutz, caught at tree-top level at La Cuchilla, South America, has indicated the necessity of exploring this stratum of a forest. Much of the present investigation was therefore devoted to the study of the habits of mosquitos at different levels and in order to observe possible differences in breeding, two series of containers were erected at heights or 10, 20, 30, 40 and 50 feet up in the trees. The first series consisted of either bamboo sections or rectangular wooden containers (five inches long) slung on a rope at the afore-mentioned heights up a tree and removable by a descending rope slung over a pulley fixed at 50 feet. There was a tendency for this system to swing out into mid-air, and breeding did not take place very freely. The second series consisted of natural rot holes sawn out of trees together with a large thickness of wood and fixed with wire at similar intervals on the trunk of another tree. This proved more satisfactory, and the holes were much favoured for ovipositing. In addition, bamboo sections were placed at 55 and 60 feet on the permanent "tree-top" platform (see p. 478). All these containers were filled with water twice a week and fourth-stage larvae were removed weekly.

Rock Holes.

Scattered in many parts of the forest are large granite boulders usually in deep shade and covered with ferns, lichens and moss (Plate XVII, fig. 1) but occasionally in open sunlit glades. Five groups of the former and one of the latter were chosen for observation weekly. The water level was maintained in the same way as that of the tree-holes and fourth-stage larvae were collected for examination. The fauna of the shady holes approximated closely to that of tree holes; the sunlit rocks, however, presented a completely different picture.

Plant Axils.

The bulk of the undergrowth of Kaimosi forest consists of dracaenas (*D. reflexa* var. *nitens,* Baker), and the axils of these were found to be a most prolific source of certain species of mosquitos. Samples were taken at least once a month with a pipette and larvae were removed for identification. It may be noted here that *Aëdes* (*Stegomyia*) *simpsoni,* Theo., was never found breeding in the *Dracaena* of the forest, though it was common in the same species of *Dracaena* planted as a hedge round native huts not far from the forest border. Haddow (1945) in recent observations in Uganda on *A. simpsoni* has found adults only on the external fringe of the forest, though it is very common in banana plantations just outside. The wild banana (*Musa livingstoneana,* Kirk) was present in very much smaller numbers and was included in the survey. Practically no leaf pool breeding was found.

Rivers.

Numerous streams flow through the forest and provide a characteristic mosquito fauna under three sets of conditions (i) shade, (ii) sunlight and (iii) dry weather conditions with formation of rock pools. Searches were made once a week and larvae collected.

A routine was also established for the collection of adult mosquitos and catches were made in the following ways:—

Catches on Ground Level.

We used native children as bait employing the technique used by Dr. Haddow in the Bwamba forest in Uganda. Catches were made once a week in many different parts of the forest, and extremely diverse results were obtained. Adults were scarce in the deeper parts of the forest and on the fringe of dense, untouched forest. Secondary growth and portions at the northern end where the high canopy was much broken provided much higher catches. The morning from about 9 a.m. to noon (local time) proved the most prolific time of the day. A few night catches were undertaken with entirely negative results. From July to September, 1944, a series of morning and afternoon catches* were compared:—

31 morning catches gave 386 mosquitos, *i.e.,* 12 each catch.
17 afternoon catches gave 126 mosquitos, *i.e.,* 7 each catch.
(The bulk of these catches consisted of *A.* (*S.*) *apicoargenteus.*)

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* The meagre number of mosquitos caught makes analysis into "clock-hours" and "man-hours" statistically worthless. In general, each catch represents 3 hours work by 2 men.

Miscellaneous Catches.

The only satisfactory way of determining relevant adult incidence is that mentioned in the preceding paragraph, whereby only mosquitos in the actual process of biting are collected. Traps baited with suitable animals theoretically should be useful, but in practice, as used by us in this forest, they attracted nothing. On occasions, undergrowth, rocks, tree trunks, river banks, etc., were searched for adult mosquitos.

Hut and Tent Catches.

The methods used in malaria surveys for determining Anopheline incidence, *e.g.*, collections in huts or tents, proved to be completely useless for sylvan mosquitos. Two huts were built in the forest but not a single mosquito was found in them during daily searching for three months and they were abandoned. Dr. A. J. Haddow and one of us made observations in a lighted tent throughout a night in 1941 in this forest and found only Anophelines. The absence of *Aëdes* mosquitos was confirmed in similar circumstances elsewhere in the forest on subsequent occasions. In routine collections in huts in rural areas, we have, however, taken tree-hole breeding *Aëdes* (*africanus, longipalpis* and *ingrami*) in small numbers (Garnham & Harper, 1944). Early morning searches of the native quarters of our camp at the forest edge revealed a seasonal incidence (from about March to June) of *Anopheles gambiae.*

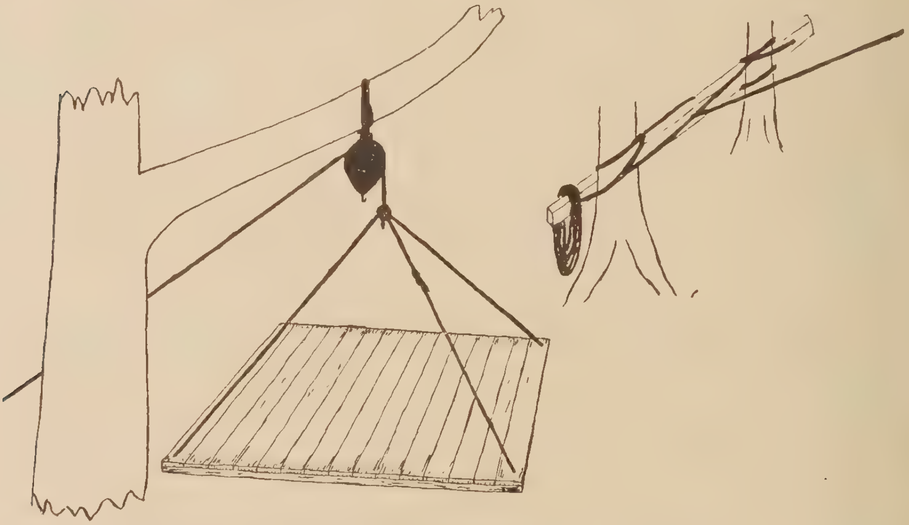

FIG. 2.—Movable tree platform capable of holding two observers.

Catches on High Platforms.

A fixed wooden platform capable of holding about seven or eight people was built 55 feet up a tree in the depth of the forest (Plate XVI, fig. 1), and a ladder was nailed to the trunk to provide easy access. A movable platform was also constructed so that observations at different levels could be carried out in different parts of the forest. The latter platform is slung over a pulley (fig. 2) and is capable of carrying two people. Routine catches were made on the former and the latter was used principally to compare ground and high level catches. The comparative incidence of different species of mosquitos will be discussed later. It may be noted here that *Simulium neavei* was found frequently on the 55 ft. platform and *Culicoides* sp. on the 43 ft. one. In general, mosquitos appeared to be more numerous on top, as the following figures show:—

Twelve ground catches yielded 138 mosquitos or 11 each catch.

Sixteen simultaneous " nest " catches yielded 283 mosquitos or 18 each catch.

Another series gave the following results: —

Twenty-one ground catches yielded 50 mosquitos or 2 each catch.
Twenty-three " nest " catches yielded 96 mosquitos or 4 each catch.

This phenomenon and the relative predominance of mosquitos in lighter bush adjacent to the main forest appear to be examples of the " edge effect " of Leopold, 1933 (*i.e.*, the place of concurrence of two vegetational types is the place most favourable to animal population).

Habits and Prevalence of Mosquitos.

Incidence of Species.

The notes which follow summarise the results of our observations on the mosquitos of the Kaimosi forest, together with some information as to their incidence, etc., in the adjoining mountain forests of Nandi and the Mau (rising to 9,000 feet) and in fringing forests of the rivers below. The trees are very different in the higher mountain forests and comprise chiefly olives (*Olea hochstetteri*, Baker), *Polyscias kikuyuensis*, Summerhayes, *Dombeya masterii*, Hk. f., *Euphorbia*, fig, cedar, *Podocarpus*, and at the highest altitude, bamboo. Mosquito breeding is very greatly reduced in this type of forest, both in trees and in plant axils.

Immediately after the name of each species is given the number of larvae and adults examined in the course of the investigation. Special rearings (numbering many thousands) for determination of species are not included.

Anopheles (*Anopheles*) *implexus*, Theo. Larvae 45, adults 13.

This striking mosquito is the only Anopheline found in the forest that bites man commonly. It attacks viciously in the day time. It breeds in river pools in deep shade, chiefly in the drier seasons. It was once found in a tent at night.

Anopheles (*Myzomyia*) *natalensis*, Hill & Haydon. Larvae 4, adults 12.

Although adults of this species were once caught in a tent, they do not apparently attack man; they were found not uncommonly sheltering under overhanging banks and under a bridge by a river. Larvae were found in shady pools in the river.

Anopheles (*M.*) *nili*, Theo. Larvae 22, adults nil.

A rare river-breeding species in this locality, though in the final extension (Chepalungu) of this forest and mountain system, 80 miles to the south, it is common both as adults in huts and larvae in streams.

Anopheles (*M.*) *marshalli* var. *gibbinsi*, Evans. Larvae 1, adults nil.

A single larva in a rock pool was recorded.

Anopheles (*M.*) *keniensis*, Evans. Larvae 78, adults 43.

Although this Anopheline does not attack man in Kaimosi, at certain seasons it is found in large numbers resting on the damp trunks of trees in deep forest. Larvae are commonly found in rivers. A brief description of the egg (hitherto undescribed) is given in the Appendix.

Anopheles (*M.*) *gambiae*, Giles. Larvae 2, adults 42.

This species is the malaria vector of the locality. It occurs in small numbers only and was never found in adult catches in the forest.

Megarhinus.

Mosquitos of this genus are widely distributed throughout the Kaimosi forest including the " tree-top " level, where on one occasion an adult was seen flying. The only other occasion on which a wild adult was observed was surprisingly enough in a house in Kisumu when a female *M. brevipalpis* was caught at sundown in a bedroom on the second storey. The larva is found usually singly but sometimes in twos or threes in tree holes and in the artificial containers referred to above. Its predacious habits are well known, but in order to get an approximate idea of the number of *Aëdes* larvae that it can consume, a series of observations were made and these showed that third- or fourth-stage *Megarhinus* larvae frequently eat 20 *A. aegypti* larvae (fourth-stage) in a single night. One *Megarhinus* consumed 195 similar larvae in the 12 days before pupation. When pupae were substituted for larvae, *Megarhinus* did not devour more than four (whole pupae) in a night. These results indicate that *Megarhinus* is a more voracious predator than *Culex* (*Lutzia*) *tigripes*, G. & C., which Haddow (1942) showed consumed on an average only five fourth-stage larvae (*A. gambiae*) overnight.

Larval and pupal stages of this genus are unusually prolonged in Kaimosi. The period from the newly hatched larva to pupa is unknown but is probably three or four weeks. Records of the pupal stage demonstrated an average duration of nine days, though this was sometimes prolonged up to three weeks. It was never shorter than six days.

The systematic position of the members of the " *brevipalpis* " group occurring in this forest is difficult to establish, because of the wide variations found amongst them. The graduations in the type form of *M. brevipalpis* extend until specimens are found which approach the sub-species *conradti* in morphology. With *M. barbipes* considerable variation is also found. Further notes on these points will be found in the Appendix (p. 495). One *Megarhinus* larva was found extensively parasitised with the spores of *Coelomomyces* sp.

Megarhinus brevipalpis, Theo. Larvae 24, adults nil.

This species was found more frequently in artificial containers at high levels than in tree-holes. It particularly favoured heights of 50 feet and above. It was found on one occasion however in a hole in a granite boulder deep in the forest.

Megarhinus barbipes, Edw. Larvae 131, adults nil.

The female larva and pupa of this species were found for the first time (*vide* Appendix). It is by far the commonest *Megarhinus* of the Kaimosi forest and was found breeding extensively in tree-holes, artificial containers and pools in granite boulders. It is not found so exclusively in the higher strata as the foregoing species. It favours the larger, more bowl-like, tree-holes and in particular the dark brown water contained in a fallen tree (Plate XVI, fig. 4). One such tree had a small orifice leading to a cavity seven feet in length.

Megarhinus, sp. indet. Larvae 13, adults nil.

This mosquito belongs to the *lutescens* group (*vide* Appendix, for a brief description of the adult male and female, larva and pupa). It was found breeding in a hole in a fig tree, in other tree-holes, in bamboo sections at forty feet and in the " natural " containers at higher levels.

Harpagomyia taeniarostris, Theo. Larvae 4, adults nil.

Larvae were found on one occasion only in the axils of a wild banana near the edge of the forest.

Uranotaenia ornata, Theo. Larvae 6, adults nil.

Larvae were found in the axils of the wild banana in conjunction with *Culex musarum*.

Uranotaenia fusca, Theo. Larvae 19, adults nil.

A common inhabitant of rock pools in streams in the forest.

Theobaldia (*Theomyia*) *fraseri*, Edw. Larvae 421, adults nil.

The strikingly blue larva of this species was found constantly in the hole in the fallen tree described above under *M. barbipes*. It was also taken rarely in ordinary tree-holes.

Ficalbia (*Mimomyia*) *plumosa*, Theo. Larvae nil, adults 1.

One female only was collected in routine adult catches in second growth forest.

Taeniorhynchus (*Coquillettidia*) *versicolor*, Edw. Larvae nil, adults 1.

A single female was caught in a morning catch on the movable platform at 30 feet.

Taeniorhynchus (*C.*) *maculipennis*, Theo. Larvae nil, adults 11.

Adults of this species attack man fairly frequently at ground level in the forest.

Taeniorhynchus (*C.*) *aurites*, Theo. Larvae nil, adults 3.

An uncommon biter of man at ground level in the northern part of the forest.

Aëdes (*Finlaya*) *longipalpis*, Grünb. Larvae 432, adults 38.

This important species comes third in order of prevalence in tree-hole breeding. It is rather more selective in its breeding habits than the other common *Aëdes*, choosing tree-holes or artificial containers which are well above the ground. It was found most often in a tree-hole 18 feet high (Plate XVI, fig. 3), whilst in the crevices in ground buttresses of *Craibia elliottii*—a common haunt of other species—it was almost invariably absent. The larvae were found very rarely in high pools in shaded rock boulders. This high level preference is shown by the adult insect also, as the following figures show:—

Fixed platform (55 feet)	21 captures.
Ground	no captures.

A second series gave:—

Platform	11 captures.
Ground	7 captures.

Aëdes (*F.*) *ingrami*, Edw. Larvae 17, adults 31.

Although few collections of larvae from tree-holes were recorded, *A. ingrami* adults are not uncommon in catches made in secondary growth forest, where the canopy is much broken. It is less exclusively sylvan than many other species.

Aëdes (*Stegomyia*) *aegypti*, L. Larvae 253, adults 19.

Much to our surprise, we found this domestic species scattered rather profusely through the forest. It was much easier to collect it in the forest than in the native villages just outside, where surveys gave the following negligible results:—

1. May, 1943: 85 huts searched. *A. aegypti* larvae found once. Index 1·2 per cent.
2. June, 1944: 100 huts searched. No *A. aegypti* found. Index nil.

Receptacles searched comprised 165 water-pots and 32 tins, etc. Larvae of *A. aegypti* were found once in peridomestic bananas and once in rock pools in this village survey.

This mosquito has a wide range of breeding places in the forest of which ordinary tree-holes are least favoured. The following figures of the number of records from the different types of breeding place give an approximate idea of the breeding incidence: 2 from 30 special tree-holes, 5 from rock pools in deep shade, 8 from rock pools in sunlight, 11 from tree stumps, etc., and 34 from pools in rivers.

It specially selects two types of breeding place—holes in recently felled trees at the forest edge (Plate XVII, fig. 2) and rock pools in rivers which are drying up in drought periods. In either of these two conditions, it can be recovered fairly constantly. It was never found in the artificial containers placed at different heights above the ground; it thus appears to be a consistently low level breeder.*

Larvae were frequently found a mile or more inside the forest and at this distance also from human habitations. Experiments were devised to test its penetration from the forest fringe to different distances inside. Groups of bamboo sections were placed at intervals of 100 yards. The first experiments were vitiated by the omission of a preliminary sterilisation; the presence of desiccated eggs from previous experiments entirely falsifying the results (indices of 27 per cent. and 18 per cent. were obtained). We wish to emphasise most strongly the danger of this fallacy wherever the " bamboo pot index " is used. Later experiments were entirely negative for *A. aegypti* though two-thirds of the pots became infested with larvae of other species (chiefly *Eretmapodites*).

The dry weather breeding of *A. aegypti* in river beds a long way inside the forest is most unusual, and such places are not included in Hopkins' (1936) list of breeding places. Yet in Kaimosi it is one of the most favoured sites.

The adult has the same elusive habits here as in many parts of Kenya. During the period of investigation it was not once found in huts; it formed only a small proportion of the total adult catches in the open and it was most often to be seen emerging from the pupa in rock pools. A single specimen only was caught on the tree platform (43 feet).

Aëdes (*S.*) *apicoargenteus*, Theo. Larvae nil, adults 644.

The close resemblance of this species to the next, *A. fraseri*, the wide variations that exist in both (*vide* Appendix) and the bad differentiation in Edwards' key (1941) inevitably led to some confusion in the earlier identification of the adults of these two species. Fortunately the larvae are easily separable. The larva of *A. apicoargenteus* was not recovered from the southern end of the forest (the locality where routine searches were made) but it was found in a few special searches at the northern end, in holes in fallen trees. In forest at Kisii many miles to the south, we have collected it in large numbers in ordinary tree-holes. Both these places carry second growth forest with a broken canopy, and it appears that this species prefers a lighter type of forest than does *A. fraseri*, which is essentially an inhabitant of dense untouched forest. *A. apicoargenteus* was the dominant species in many adult catches and bites man readily. In comparative ground and platform catches it occurred in the proportion of two to three respectively. Wild caught females survived for long periods in captivity when fed on alternate days on blood and kept in a moist atmosphere at a temperature varying between about 25°C. and 30°C. Three specimens lived for 50 days and one for 55.

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* *Aëdes aegypti* does not show this preference for low breeding places everywhere; in Mombasa, Teesdale (1945) has recorded breeding on many occasions in bamboo pots placed on the crown of coconut palms.

Aëdes (*S.*) *fraseri*, Edw. Larvae 2,843, adults 253.

The larva of this species was first recorded in this investigation (*vide* Appendix). It is a prolific breeder in the dense part of the forest in tree-holes and holes in shaded granite boulders. Height does not play an important part in choice of breeding sites; the larvae are found in large quantities both in boulders or bamboo sections on the ground and in artificial receptacles at 60 feet. It was rarely found in rock pools exposed to sunlight in the middle of the forest. Larvae of this species (together with those of *A. capensis* and *A. deboeri* subsp. *demeilloni*) hatched from desiccated eggs in vegetable débris removed from dry rot holes. Adults were numerous in catches made only in *deep* forest; they were caught on the ground and on the 55 foot platform in a proportion of 3 : 5.

Aëdes (*S.*) *deboeri* subsp. *demeilloni*, Edw. Larvae 504, adults nil.

Confusion exists in the current descriptions of this subspecies, of the type form and of *A. dendrophilus*; dissection of the male terminalia enabled us, however, to assign this Kaimosi mosquito to subsp. *demeilloni* (*vide* Appendix). It is a widespread and fairly common forest breeder at all levels and in all kinds of tree-holes except the large hole in the fallen tree (with high organic content). It was uncommon in the shady rock holes and absent in the sun exposed holes. Adults were never found.

Aëdes (*S.*) *bambusae*, Edw. Larvae 53, adults 5.

This species, though not common at Kaimosi, shows a wide range of breeding. Larvae were taken in tree-holes (including holes in buttresses), in the deeply shaded holes in granite boulders, in containers at different heights up to sixty feet and in bamboo pots placed on the ground in the forest. A few adults only were caught biting at ground level. Hopkins (1936) refers only to breeding in bored bamboos, and it is probable that the species collected here is a variety (*vide* Appendix). *A. bambusae* is not exclusively sylvan in its habits; we have caught it also in houses in Kisii.

Aëdes (*S.*) *africanus*, Theo. Larvae 351, adults 39.

This *Stegomyia* is one of the known (laboratory) transmitters of yellow fever (League of Nations, 1935), and its habits are therefore of importance. Both in the immature and adult form it exhibits striking peculiarities. It is moderately common in Kaimosi. While the majority of the Kaimosi mosquitos show little change in density throughout the year, the numbers of this species fluctuate with the season. It appears to be most common at the end of the "long rains" (from August to November). Its favoured breeding places are pools in the buttresses of *Craibia elliottii* (Plate XVI, fig. 2). It is five times commoner in such ground-level tree-holes than in higher holes, though larvae have been found on occasion in containers up to 50 feet. The shaded granite holes fairly often hold this species. The adult mosquito, on the other hand, is most often a denizen of the tree-tops. In a series of observations with the movable platform, eighteen specimens of *A. africanus* were found on the platform and none on the ground beneath. This species is established in many rural and semi-urban districts in the vicinity of Kaimosi forest where it breeds both in tree-holes and in domestic containers.

Aëdes (*S.*) *vittatus*, Big. Larvae 49, adults 3.

This mosquito was found fairly often in the recognised typical breeding places, *viz.*, rock pools. It is absent, however, in the shady pools in granite boulders and in all tree-holes. Adults have rarely been found, biting, in catches in the vicinity of breeding places.

Aëdes (*Aëdimorphus*) *marshalli*, Theo. Larvae 3, adults nil.

An unimportant species found in the larval stage in three holes and in a bamboo section.

Aëdes (*A.*) *capensis*, Edw. Larvae 5,776, adults 14.

This species (apparently Edwards' type A) is the commonest tree-hole breeder in Kaimosi. Large numbers of larvae could be collected at any season, except the driest, in practically every type of tree-hole at any height. It did, however, dislike the deep amber-coloured water of the fallen tree. It was very common in the shady granite holes in deep forest though it was rare (occurring four times) in rock pools outside. It was also found (twice) in the axils of wild bananas. Natural and artificial (bamboo) containers at heights up to 60 feet were infested with this species. The adult does not attack man every often, and it is found very rarely in comparison with the larvae. One specimen was collected, biting, on the 43 foot platform.

Aëdes (*A.*) *haworthi*, Edw. Larvae nil, adults 3.

Though common in other parts of Kenya, one male and two female adults only of this species were collected in Kaimosi—in the more open part of the forest.

Aëdes (*A.*) *tarsalis*, Newst. Larvae 307, adults 1.

A single adult was collected in light forest. It was difficult to classify the larva of this species originally owing to an apparent confusion in the description of *A. tarsalis* and *A. filicis*, G. & D. (*vide* Appendix). Larvae were common in rock pools in the forest, including both sunlit and deeply shaded ones, and were even more common in pools beside rocky streams.

Aëdes (*A.*) *quasiunivittatus*, Theo. Larvae 5, adults 19.

Larvae were uncommonly taken in river pools. Adults were obtained in ground catches in the more open parts of the forest.

Aëdes (*Banksinella*) *circumluteolus*, Theo. Larvae nil, adults 63.

No attempt was made to differentiate this species from *A.* (*B.*) *lineatopennis*, Ludl. Adults were numerous in ground catches in secondary growth forest; none were found on the tree platforms.

Aëdes (*Dunnius*) *albomarginatus*, Newst. Larvae nil, adults 30.

Males and females of this mosquito were common in a certain patch of light forest on the border of the main Kaimosi forest whilst they were less common elsewhere. Females bite man readily. Searches of neighbouring tree-holes failed to reveal larvae. The systematic position of this species has been clarified by an examination of the male terminalia (*vide* Appendix).

Eretmapodites semisimplicipes, Edw. Larvae 1,052, adults 22.

The commonest breeding places of this mosquito are the fern-hung holes in granite boulders deep in the forest and in bamboo sections placed on the ground. In such sites the larvae are always very numerous. It is less common in tree-holes and when present is usually confined to holes near the ground. It was never found above 20 feet. Another common breeding place is the fluid in the top of tree-stumps. This fluid comprises largely the sap which has a most pungent odour and an alkaline reaction. In such sites it is usually accompanied by a heavy culture of *Culex nebulosus*. Larvae are found infrequently in the dry season in rock pools by the side of streams in the forest. The classical breeding place (large fallen leaves) of this group is practically absent at Kaimosi, and only on one occasion were (five) larvae found in a leaf pool. The adults were collected in a large proportion of forest catches on the ground but not on platforms. The identity of this species was determined by a series of isolations from larvae followed by the examination of the male terminalia.

Eretmapodites leucopus subsp. *productus*, Edw. Larvae 26, adults 3.

The larvae of this species were originally identified as *E. oedipodius*, Graham, but by breeding them out and dissecting the male terminalia, the correct identification was obtained. This species is relatively uncommon though its larvae were found in a variety of situations, including axils of *Dracaena* plants (13 larvae), bamboo sections placed on the ground in the forest (6). shaded granite holes (5) and tree-holes (2). Adults were caught biting in the daytime at ground level.

Eretmapodites, sp. indet. Larvae 494, adults 32.

The Dracaenas of Kaimosi produce large numbers of a species resembling *E. dracaenae*, Edw., but possessing a very different type of male terminalia (*vide* Appendix). This species has a more restricted habitat (*i.e.*, *Dracaena* axils) than that of practically any of the other sylvan mosquitos found in Kaimosi. It was only once found elsewhere, in a small hole in a tree (*Bosquiea phoberos*), six feet from the ground and with shoots covered with leaves growing out of the hole. Adults were comparatively common in ground catches and bite man readily. Breeding is restricted to *Dracaena* growing in the forest and does not occur in plants outside.

Culex.

It is not proposed to describe in any detail the majority of the species of this genus encountered in the investigation. Most of them breed in rivers or pools.

Culex (*Lutzia*) *tigripes*, Grp. Larvae 180, adults 4.

In addition to the usual breeding sites, this common species was found eight times in tree-holes and once in a bamboo section placed on the 55 foot tree platform.

Culex (*Neoculex*) *salisburiensis*, Theo. Larvae 12, adults nil.

The larva of this species exhibits constant slight differences in morphology from the published description (*vide* Appendix).

Culex (*N.*) *insignis*, Carter. Larvae nil, adults 1.

Culex (*N.*) *albiventris*, Edw. Larvae 2, adults nil.

Two larvae only were found in the basin in a low fork of a tree (*Craibia elliottii*).

Culex (*N.*) *adersianus*, Edw. Larvae 384, adults nil.

A selective breeder in large tree-holes near the ground (including fallen trees). It does not breed in bamboo sections nor in rock holes. It is commonest during the heavy rains.

Culex (*Culiciomyia*) *nebulosus*, Theo. Larvae 778, adults 12.

This species is an ubiquitous breeder, despising nothing except running water and *Dracaena* axils. It is fairly common in both sunlit and shaded holes in granite boulders. Larvae were most numerous in the "natural container" at 40 feet, though present also at 60 feet. Adults were collected on the 55 foot platform as well as at ground level. *C. nebulosus* shows a well marked seasonal incidence in this locality, being most prevalent in the dry weather, as the following figures show:—

In nine "wet" months, *C. nebulosus* was collected from 21 breeding places (trees and rock holes), *i.e.*, an average of 2·3 per mensem.

In four "dry" months, *C. nebulosus* was collected from 69 breeding places (trees and rock holes), *i.e.*, an average of 17 per mensem.

Culex (*Culiciomyia*) *macfiei*, Edw.	Larvae 4, adults nil.

A rare inhabitant of containers at 50 and 55 feet.

Culex (*C.*) *annulioris*, Theo.	Larvae nil, adults 1.
Culex (*C.*) *duttoni*, Theo.	Larvae 13, adults nil.
Culex (*C.*) *univittatus*, Theo.	Larvae nil, adults 24.
Culex (*C.*) *simpsoni*, Theo.	Larvae 13, adults nil.
Culex (*C.*) *striatipes*, Edw.	Larvae nil, adults 1.
Culex (*C.*) *pipiens*, L.	Larvae 18, adults nil.
Culex (*C.*) *trifilatus*, Edw.	Larvae 535, adults 4.

In addition to the breeding places mentioned by Hopkins (1936) larvae were found on 43 occasions in tree-holes and on 30 in shaded rock pools in the forest.

Culex (*C.*) *antennatus*, Beck.	Larvae 7, adults nil.
Culex (*C.*) *decens*, Theo.	Larvae 5, adults nil.
Culex (*C.*) *perfuscus*, Edw.	Larvae 1, adults nil.
Culex (*C.*) *ingrami*, Edw.	Larvae 14, adults nil.
Culex (*C.*) *pruina*, Theo.	Larvae nil, adults 2.

Two females were caught biting in the afternoon in light forest.

A summary of the incidence of the commoner species is given in Tables II and III.

TABLE II.

Habits of common sylvan Mosquitos (Larvae). (In order of prevalence.)

Species	Principal Breeding Places	High	Low
Aëdes capensis	Tree-holes, granite holes* ...	+	+
A. fraseri	,, ,, ,, ...	+	+
E. semisimplicipes	,, ,, ,, ...	—	+
C. nebulosus	Ubiquitous	+	+
C. trifilatus	River pools, tree-holes, granite holes.*	—	+
A. deboeri demeilloni	Tree-holes	+	+
A. longipalpis	,, ...	+	—
T. fraseri	,, ...	—	+
C. adersianus	,, ...	—	+
A. africanus	,, granite holes*	—	+
A. tarsalis	Pools in streams, granite holes* ...	—	+
Eretmapodites sp.	*Dracaena* axils	—	+
A. aegypti	Pools in streams, tree stumps ...	—	+

* Holes in granite boulders deep in the forest.

Note.—In addition to the above high breeders, Megarhines, especially *M. brevipalpis* and *Aëdes* (*S.*) *bambusae* are also found fairly often in the highest pots (at 60 feet).

We suggest the term "acrodendrophily" (*) for the tendency that is shown by certain sylvan mosquitos for haunting tree-tops. Thus *A. longipalpis* may be described as obligatorily acrodendrophile in both mature and immature stages, whilst *A. africanus* has a restricted acrodendrophily, in reference solely to the adult form.

TABLE III.

Habits of common sylvan Mosquitos (Adults). (In order of prevalence.)

Species	"Tree-top"	Ground
Aëdes apicoargenteus	+ +	+
A. fraseri	+ +	+
A. circumluteolus	—	+
Anopheles keniensis	—	+
Aëdes africanus	+ +	Rare
A. longipalpis	+ +	Rare
Eretmapodites sp. indet.	—	+
Aëdes ingrami	—	+
A. albomarginatus	—	+
Eretmapodites semisimplicipes	—	+
Aëdes aegypti	Rare	+

Density of Breeding.

Density of adult mosquitos in the forest has been discussed on pages 477-479. The figures for adults bear little relation to larval incidence. Some idea of the latter was obtained by intensive searching of measured acres of forest, and the results of five surveys are given in Table IV.

TABLE IV.

Mosquito Breeding in five Plots of one Acre of Forest.

Date	Number of trees with holes containing water	With larvae	Number of *Dracaena* with water in axils	With larvae	Remarks
June, 1943 ...	4	3	360	48 (*i.e.* 13 per cent.)	Not all *Dracaena* searched.
Aug., 1943 ...	2	1	1,123	162 (*i.e.* 14 per cent.)	Half the *Dracaena* searched.
Nov., 1944 ...	3	2		Not examined	Total of 32 trees.
Nov., 1944 ...	4	3		Not examined	Total of 76 trees.
Nov., 1944 ...	Nil	Nil		Not examined	Total of 44 trees.

The tree-hole breeding was much less than was expected while the *Dracaena* breeding was greater. About half a dozen larvae was the average for a *Dracaena*—so the total output of *Eretmapodites* in this forest must be enormous. The number of larvae in tree-holes varied considerably, and a sample catch in a number of the special tree-holes which had been left undisturbed for three months is shown in Table V.

(*) A name kindly devised for us by Dr. A. J. Jex-Blake.

TABLE V.

Density of Larvae in Tree-holes (November, 1944).

Number of Tree-holes	Width of hole in inches	Number of larvae	Number of pupae
1	5	26	—
9	6	14	2
12	2	7	—
14	4	2	—
15	4	2	—
16	12	117	—
18	6	165	1
29	7	93	2
30	5	48	10

The larval content of holes in granite boulders in the forest is usually high, approximating to the larger figures for tree-holes shown in Table V. These numbers are considerably lower than those quoted by Wijesundara (1942) for a tree-hole in Ceylon, which he assessed at an output of 400-500 adults per week.

Chemical Composition of Water of Tree-hole Breeding Places.

Samples of water from characteristic tree-holes were analysed in our temporary laboratory at Kaimosi by the Tidy process for organic matter (oxygen absorbed from permanganate for four hours at 27° C.). This figure is regarded by Thomson (1941) as being one of the most useful for work on Anopheline ecology. Only a few samples were tested and the results are given in Table VI. The very large quantity of oxidisable matter (which did not include nitrites or iron) present in the *Theobaldia fraseri* breeding place is noteworthy. *Aëdes capensis* and *A. fraseri* bred in water containing up to 24 parts of oxidisable matter per 100,000. The latter sample contained iron, as shown by the potassium ferrocyanide test. For the majority of species, it is probable that conditions like height, shade, shape, size, etc., play a more important part in determining selection of breeding place than does the chemical constitution of the water.

TABLE VI.

Oxidisable Matter in Forest Breeding Places.

Breeding place	Oxidisable matter in 100,000 parts of water	Species of larvae
Tree 9	2·9	*Aëdes aegypti. A. africanus.*
,, 13	1·6	*A. fraseri. A. capensis.*
,, 12	5·2	*A. fraseri. A. capensis. A. longipalpis.*
,, 14	1·8	*A. africanus. Megarhinus* sp.
,, 16	1·8	*A. capensis. C. adersianus.*
,, 29	4·0	*C. adersianus. Megarhinus* sp.
,, 24	24·0	*A. capensis. A. fraseri.*
T. ,, 17	79·3	*C. adersianus. ~~A~~. fraseri.*
Rock Hole A	2·7	*A. capensis. A. tarsalis.*
,, ,, B	2·9	*A. capensis. A. fraseri.*

Sylvan Mosquitos in adjacent Forest Areas (fig. 3).

The variegated picture of mosquito breeding disappears once Kaimosi is left. The rain-forest of Kaimosi is replaced, a few miles away and in a rise of 1,000 feet or more, by the dry mountain type of forest and here in Nandi (6,500-7,000 feet) the characteristic species is *Aëdes (F.) pulchrithorax*, Edw. On one occasion in this locality (at 6,500 feet) numerous *A. aegypti* larvae were found in a small rot hole and a much undersized adult was seen resting on the surface of the water. This appears to be one of the highest records for the breeding of this species.

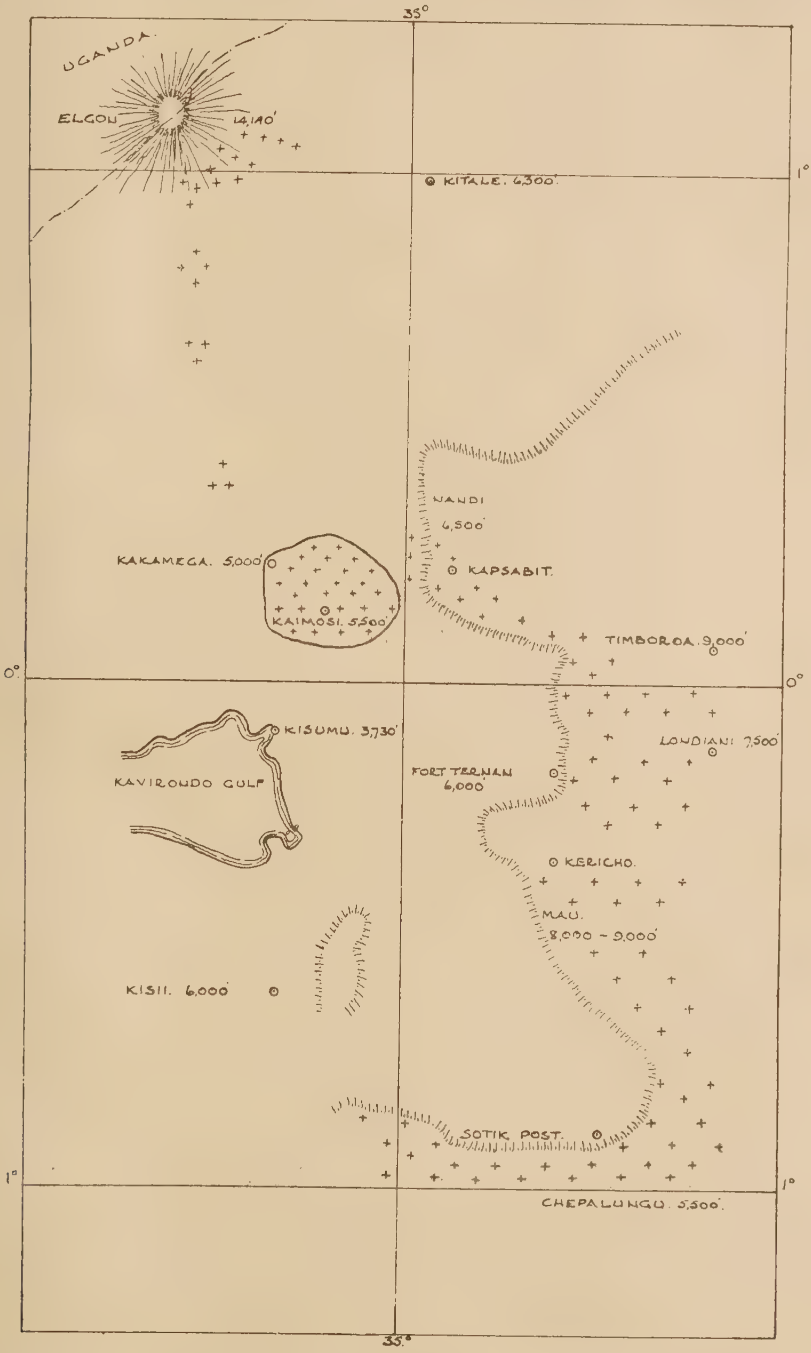
35°
UGANDA
ELGON
14,140'
KITALE. 6,300'
1°
NANDI
6,500'
KAKAMEGA. 5,000'
KAPSABIT.
KAIMOSI. 5,500'
TIMBOROA. 9,000'
0°
0°
KISUMU. 3,730'
LONDIANI 7,500'
KAVIRONDO GULF
FORT TERNAN
6,000'
KERICHO.
MAU.
8,000 – 9,000'
KISII. 6,000
SOTIK POST.
1°
1°
CHEPALUNGU. 5,500'
35°

FIG. 3.—Sketch map of Kaimosi forest in relation to surrounding forests (marked +) and mountains.

A further rise in altitude to the Mau forests (8,000-9,000 feet) changes the fauna again. Here the characteristic tree-hole breeder is *A.* (*A.*) *kapretwae,* Edw., whose larva was first found in this investigation (*vide* Appendix). *Anopheles* (*M.*) *garnhami,* Edw., *A.* (*M.*) *christyi,* N. & C., *C.* (*C.*) *andersoni,* Edw., and *C.* (*C.*) *toroensis,* E. & G., are common pool and swamp breeders in the vicinity of the forest at this altitude, whilst *A.* (*M.*) *ardensis,* Theo., is found on the western slopes of the Mau. In the furthest extension of the forest, *viz.* Chepalungu, although the altitude has now sunk to the Kaimosi level of 5,500 feet, the rich fauna of the latter does not reappear. The forest is of a poor quality with a broken canopy and catches revealed only *Aëdimorphus* and one *Stegomyia—A. africanus.*

Two other forests remain to be mentioned and are of interest because they are about the same height as that of Kaimosi. Second growth forest at Kisii provides large numbers of *A.* (*S.*) *apicoargenteus* and *A.* (*S.*) *bambusae* (in both immature and mature stages); *A.* (*S.*) *africanus, A.* (*S.*) *aegypti, A.* (*S.*) *simpsoni* and *A.* (*A.*) *marshalli* also occur. In the fringing forest of streams flowing down from Tinderet at Fort Ternan, sylvan species are common and include the following:—

A. (*S.*) *aegypti, A.* (*S.*) *metallicus,* Edw., *A.* (*S.*) *africanus, A.* (*B.*) *circumluteolus, Eretmapodites* sp. indet., *C.* (*C.*) *fatigans,* Wied., *C.* (*C.*) *toroensis,* E. & G., *A.* (*S.*) *simpsoni* and *C.* (*C.*) *musarum;* the last two as larvae in cultivated banana axils, the remainder as adults.

Common widespread mosquitos have been omitted from the above list, which does not purport to give a complete picture of the fauna.

Kaimosi Species in relation to Zoogeography.

Kaimosi lies at the junction of the East and West African sub-regions (Edwards, 1941) and is just inside the Eastern Montane District. Many species of mosquitos in Kaimosi belong to the western sub-region and have not been reported as far east before. Table VII gives a list of these species. Their isolated occurrence here can be explained on the assumption that at one time the Kaimosi forest was linked with similar country stretching through Uganda to the Congo forests, whilst Lake Victoria, the high Kenya plateaux and the northern deserts barred further diffusion eastwards.

TABLE VII.

Occurrence of "Western" Species of Mosquitos in Kaimosi.

Species	Previous records (*).
Megarhinus barbipes	Western Uganda.
Theobaldia fraseri	W. Africa, Congo, Uganda, S. Rhodesia (variety).
Uranotaenia ornata	,, ,, ,, ,, ,,
Aëdes (*F.*) *longipalpis*	,, , ,, ,, ,,
A. (*S.*) *apicoargenteus*	W. Africa, Congo, Uganda.
A. (*S.*) *fraseri*	W. Africa, Congo, Uganda, S. Rhodesia.
A. (*S.*) *deboeri* subsp. *demeilloni* ...	Zululand (?), Uganda (Western)
A. (*S.*) *bambusae*	Uganda.
A. (*D.*) *albomarginatus*	Congo.
Eretmapodites leucopus productus ...	Congo, Uganda (Western).
E. semisimplicipes (**)	W. Africa, Uganda, Congo.
C. (*Culiciomyia*) *macfiei*	W. Africa, Uganda.
C. (*Culiciomyia*) *subaequalis*	Congo.
C. (*C.*) *pruina* (**)	W. Africa, Congo, Uganda.

(*) Taken largely from Edwards (1941).
(**) First recorded by Mrs. Van Someren from Kaimosi in 1936.

The only instance of a restricted East African lowland species in Kaimosi is that of *C. adersianus*. This species hitherto has only been found on the Coast.

It is to be noted that characteristically " western " species of trees (p. 474) and mammals (p. 475) also occur in Kaimosi.

Immunity Tests in Man and Animals.

Blood from humans and monkeys living in the forest was collected by us and sent to the Director of the Yellow Fever Research Laboratory at Entebbe for the mouse protection test. Human blood was obtained from 11 road workers employed for a minimum period of two years in the Kaimosi forest, and from 50 permanent forest residents employed by timber companies and by the Forestry Department. All sera failed to neutralise the yellow fever virus. Blood from the following adult monkeys was also sent for the mouse protection test: One baboon, five red tailed monkeys, four blue monkeys, two colobus monkeys.

All proved negative to yellow fever but it is interesting to note that the serum of one red tail neutralised Semliki forest virus (Smithburn *et al.*, 1944) and that one blue monkey was positive to either Japanese B or St. Louis encephalitis virus (Smithburn & Jacobs, 1942).

Discussion.

Findlay (1941) has pointed out the key position occupied by Kenya Colony in relation to the introduction of yellow fever and refers to the good road system linking North Kavirondo (in which district Kaimosi lies) with Uganda, Stanleyville, etc. With the ever increasing volume of traffic, the possibility of the arrival of human cases of the disease is not remote, and it is now apparent that the " soil " of Kaimosi is adequate for the establishment of the disease. *Aëdes simpsoni* is present in villages adjacent to the forest. Red tailed monkeys abound and raid the native crops, and Haddow, Smithburn, Mahaffy and Bugher (unpublished) have suggested that it is this species of monkey under such conditions which is the most important one in the jungle-man cycle. The other important species—colobus—is also present. Lastly, in the forest tree-tops, there is a known vector, *A. africanus,* ready to act as reservoir and transmitter of the virus. The meteorological conditions though not optimum are almost certainly suitable for the development of the virus in the mosquito which under the conditions prevailing in Kaimosi is likely to have a long life. The general adequacy of the environment is confirmed by the actual existence of two other closely related insect-borne virus diseases.

The prevention of the introduction of the disease into Kaimosi presents a difficult problem. Control may be considered under three headings:—

1. Prohibition of entry of non-immunised travellers. This is an impracticable measure in present circumstances.
2. Destruction of the most important animal hosts (*viz.*, red tails and colobus). In so small an area this is a possibility though it is unlikely to be fully effective.
3. Mosquito species control. In addition to the known vector (*A. africanus*), other high flying mosquitos exist whose potentialities are unknown. *A. africanus* is selective in its breeding habits, choosing pools in the buttresses of the tree, *Craibia elliottii,* and it is possible that by filling such holes a considerable reduction in the species would result. Paine (1943) attained a degree of success in mosquito control by introducing the predator, *Megarhinus splendens,* into Fiji, and it is conceivable that some reduction in the numbers of sylvan mosquitos might be obtained by increasing the facilities for the breeding of Megarhines in Kaimosi.

We do not propose to recommend the institution of any specific measures of control until the work of the Yellow Fever Research Institute, Entebbe, on jungle yellow fever in Uganda has been completed, particularly as the mouse protection test on the sera of man and monkeys indicates the absence of yellow fever at present.

Acknowledgements.

We have to thank the Hon. Director of Medical Services, Kenya, for permission to publish this paper. We are especially indebted to the staff of the Yellow Fever Research Laboratory, Entebbe, and to Mr. C. B. Symes and Mrs. E. C. C. Van Someren of the Medical Research Laboratory, Nairobi, for much advice and help. Information supplied by officers of the Forestry, Game and Meteorological Departments of Kenya is also gratefully acknowledged.

Summary.

1. The danger of the establishment of yellow fever in certain of the forests of Kenya is pointed out. Kenya has had two recognised cases of the disease in recent years.

2. The Kaimosi forest was selected as a suitable area for investigation and the general environmental conditions are described.

3. A mosquito survey was undertaken over a period of two years and particular attention was paid to the question of "acrodendrophily" *i.e.*, the preference shown by certain species of mosquitos for life in the tree-tops.

4. Five species of mosquitos—*Culex nebulosus, Aëdes capensis, A. fraseri, A. deboeri* subsp. *demeilloni* and *A. longipalpis* breed in high tree-holes; the last, almost entirely so. The many characteristically low breeders include *A. aegypti* and *A. africanus*. There is an interesting distinction between the two commoner Megarhines; *M. brevipalpis* breeds high, *M. barbipes*, low.

5. Four species of mosquitos—*A. apicoargenteus, A. fraseri, A. africanus* and *A. longipalpis* were found biting in the tree-tops; the last two being rare in ground catches.

6. Forest with a broken canopy proved best for adult catching and the morning was a better time than the (usually overcast) afternoon. Night searches gave negative results. Catches on high tree platforms appeared to be more prolific than those on the ground.

7. The following points of special interest in regard to individual species of mosquitos are summarised below:—

(i) Megarhine larvae consume about 20 fourth-stage *aegypti* larvae a night. Pupal stage lasts on an average for nine days.

(ii) *Aëdes aegypti* breeds commonly in two sites (*a*) recently felled trees at forest edge; (*b*) rock pools in rivers in drought periods. Larvae are found a mile or more inside the forest. Breeding of this species has been discovered as high as 6,500 feet.

(iii) *Aëdes apicoargenteus* was the commonest adult. Some specimens survived 55 days in captivity.

(iv) *Aëdes africanus* shows a seasonal incidence, being commonest at the end of the "long rains". Its favoured breeding places are the buttresses of the tree, *Craibia elliottii*.

(v) In the larval stage, *Aëdes capensis* is the commonest mosquito.

(vi) The characteristic breeding place of *Theobaldia fraseri* contained 79 parts of oxidisable matter per 100,000 of water.

8. Probably at least two trees per acre have rot holes with larvae and about 14 per cent. of the *Dracaena* plants are infested. Holes in shaded granite boulders are another common source of sylvan mosquitos.

9. Surveys of adjacent forest areas at different altitudes revealed striking changes in the mosquito fauna. *Aëdes pulchrithorax* is the prevalent species at the 6,500 foot level; *A. kapretwae* at the 8,500 foot; whilst in general, *A. africanus, A. aegypti* and *A. bambusae* appear to be widespread.

10. A study of the lists of mammals, trees and mosquitos indicates that the relict forest of Kaimosi contains numerous " western " species which are not found elsewhere so far to the east.

11. Immunity tests performed at the Yellow Fever Research Institute, Entebbe, demonstrated the absence of yellow fever in man and monkeys at Kaimosi. The monkeys show, however, immunity to Semliki forest virus and either Japanese B or St. Louis encephalitis virus.

12. The human inhabitants suffer from malaria and onchocerciasis (the latter carried by *Simulium neavei*) and the monkeys and fruit bats are infected with species of *Plasmodium*.

13. The Kaimosi forest from every standpoint (including meteorological) is suitable for the establishment of jungle yellow fever and possible measures of control are briefly suggested.

14. Short descriptions of new species, etc., of mosquitos are given in the Appendix.

References.

Battiscombe, E. (1936). Trees and Shrubs of Kenya Colony. Nairobi.

Davis, N. C. (1932). The effect of various temperatures in modifying the extrinsic incubation period of the yellow fever virus in *Aëdes aegypti.*—Amer. J. Hyg., **16,** pp. 163-176.

Edwards, F. W. (1930). Mosquito Notes IX.—Bull. ent. Res., **21,** pp. 287-306.

——. (1941). Mosquitoes of the Ethiopian Region, III.—London, Brit. Mus. (Nat. Hist.).

Findlay, G. M. (1941). Memorandum on yellow fever in relation to its possible introduction into Kenya. Nairobi.

Garnham, P. C. C. & Harper, J. O. (1944). The control of rural malaria by pyrethrum dusting.—E. Afr. med. J., **21,** pp. 310-320.

Haddow, A. J. (1942). A note on the predatory larva of the mosquito *Culex (Lutzia) tigripes,* G, & C. (Diptera).—Proc. R. ent. Soc. Lond., (A) **17,** pp. 73-74.

——. (1945). On the mosquitoes of Bwamba Country, Uganda, III. The vertical distribution of mosquitoes in a banana plantation and the biting cycle of *Aëdes (Stegomyia) simpsoni,* Theo.—Bull. ent. Res., **36** pp. 297-304.

Hopkins, G. H. E. (1936). Mosquitoes of the Ethiopian Region I.—London, Brit. Mus. (Nat. Hist.).

Kirk, R. (1943). Some observations on the study and control of yellow fever in Africa with particular reference to the Anglo-Egyptian Sudan.—Trans. R. Soc. trop. Med. Hyg., **37,** pp. 125-150.

League of Nations. (1935). Health Sect. of Secretariat, Epidemiological Report.

Leopold, A. (1933). Game Management. New York.

MAHAFFY, A. F., SMITHBURN, K. C., JACOBS, H. R. & GILLETT, J. D. (1942). Yellow fever in western Uganda.—Trans. R. Soc. trop. Med. Hyg., **36,** pp. 9-20.

PAINE, R. W. (1943). An introduction to the mosquitoes of Fiji. 2nd edn.—Bull. Dep. Agric. Fiji no. 22.

ROCKEFELLER FOUNDATION. [1942]. International Health Division. Annual report, 1941.

SMITHBURN, K. C., MAHAFFY, A. F. & HADDOW, A. J. (1944). Semliki Forest Virus, II.—J. Immunol., **49,** pp. 159-173.

—— & JACOBS, H. R. (1942). Neutralization tests against neurotropic viruses with sera collected in Central Africa.—J. Immunol., **4~~5~~,** pp. 9-23. 4

SOPER, F. L. (1938). Yellow fever—the present situation (October, 1938) with special reference to South America.—Trans. R. Soc. trop. Med. Hyg., **32,** pp. 297-322.

TEESDALE, C. (1945). Annual Report for 1944 on *Aëdes* control. Mombasa.

THOMSON, R. C. M. (1941). Studies on the behaviour of *Anopheles minimus*, Part IV. The composition of the water and the influence of organic pollution and silt.—J. Malar. Inst. India, **4,** pp. 63-102.

WIJESUNDARA, D. R. (1942). Notes on the Mosquito fauna of rot holes in trees and bamboo stumps in Ceylon.—J. Malar. Inst. India, **4,** pp. 451-456.

APPENDIX.

Notes on Systematics.

Most of the new material obtained in this investigation has been handed to Mrs. Van Someren, of the Medical Research Laboratory, Nairobi, for description. Very abbreviated notes, based on the diagnostic points we used in the field, are given below.

Anopheles (*M.*) *keniensis*.

Egg.—Size: Length about 0·54 mm.; breadth 0·15 mm. The egg differs from that of *A. demeilloni* in the larger number of float ridges (average twenty in *keniensis*) and particularly in the presence of large spots of black pigment scattered over the general surface. The bosses are small with an uneven distribution leaving small empty patches on the surface of the exochorion.

Megarhinus brevipalpis in Kaimosi frequently showed black supra-alar bristles (in the female) instead of gold and a large white patch on the fifth sternite sometimes practically uninterrupted.

M. barbipes exhibits a similar range of variation, particularly in regard to the colour of the scutellar and supra-alar bristles. Approximately three-quarters of the large series of specimens had golden bristles, one-eighth had mixed gold and black and the remaining eighth, black only.

Female: Differs from *M. phytophagus* in the following characters:—Sixth tergite has long lateral hairs, white; fifth sternite has an uninterrupted white patch; front and middle tarsi usually have the first segment a quarter white proximally; second and third wholly white and fourth and fifth white posteriorly except for black tip; the hind tarsus has first segment white at base, second wholly white, third white at base, fourth and fifth black.

Larva and pupa: No difference was observed from those of *brevipalpis*.

Megarhinus sp. indet. This Megarhine belongs to the *lutescens* group, but differs from the species already known by possessing a wide dark streak up the middle of the sternites, an even more expanded style than in *erythrurus* and a striking difference in the coloration of the two sexes. The female is predominantly golden and the male reddish-purple. The larva differs from *brevipalpis* in having a single or bifid sub-ventral tuft and a different arrangement of spines on the posterior margin of the saddle (*no* alteration of long and short spines in central portion).

Aëdes (*S.*) *apicoargenteus*. Variations in this species and in *A. fraseri* will be described by Mrs. Van Someren in a forthcoming publication.

A. (*S.*) *fraseri*. The larva is easily distinguished from the foregoing species by the thick fringe of the comb spines which gives them a characteristic blurred appearance, absent in *apicoargenteus*.

A. (*S.*) *deboeri* subsp. *demeilloni*. Mrs. Van Someren will be clarifying the systematic position of this mosquito. The adult exhibits a constant difference in the two sexes—the male possesses a complete median line on the scutum; in the female the line extends half way or less. The male terminalia correspond exactly to the description of the subspecies. The larva runs down in Hopkins' key (1936) to *dendrophilus* and not to *deboeri* subsp. *demeilloni*. It possesses stellate tufts on the thorax, small spines at bases of the pleural hairs and minute denticles only on the comb spines. It differs perhaps from *dendrophilus* in having head seta A bifid instead of simple.

A. (*S.*) *bambusae*. This species is widespread and in addition to Kaimosi is found at Kitale, Kisii, Equator, Mau and Elburgon. In some of these places it is a common biter of man. The scutal markings show a considerable range of variation in the number of yellow scales in the lateral patches which sometimes do not unite with the posterior lateral lines. In these circumstances the mosquito resembles *A. deboeri*, typical form, except that there are always *some* yellow scales in the large patches. A constant difference between this form and that described by Edwards is the presence of pale knee spots on the hind femora. The male terminalia are essentially similar to those of *deboeri* and subsp. *demeilloni*. Fortunately the larva of this form of *A. bambusae* shows a constant peculiarity which distinguishes it immediately from that of *A. deboeri*. This is the grouping of the pecten spines which lie in groups of two, three or more along the siphon, each group being separated from its neighbour. In our opinion, this form represents a link between *A. bambusae* and *A. deboeri* and it and *bambusae* should be regarded as subspecies of *A. deboeri*.

A. (*A.*) *kapretwae*. The larva of this species closely resembles *A. capensis* from which we were able to separate it by observing the shape of the mentum. In *capensis* the mentum is approximately rectangular, in *kapretwae* triangular. A full description will be given by Van Someren.

A. (*A.*) *tarsalis*. The larva of this *Aëdimorphus* resembles the description by Hopkins (1936) of *A. filicis* rather than that of *A. tarsalis* as follows:—Head seta A, 11-12 branches; head seta B, 6-7 branches; head seta C, 8 branches; number of comb scales, 28-35; sub-ventral tuft of siphon at $\frac{3}{5}$. Isolations made from these larvae produced pupae and adults of typical *A. tarsalis*.

A. (*D.*) *albomarginatus*. A number of males of this species was obtained and dissection of the male terminalia revealed its affinity with *A. kummi*, Edw., rather than with *A. natalensis*, Edw., as suggested by Edwards (1941). No difference could be seen in the terminalia of the Kaimosi *Dunnius* and that of *A. kummi* as originally described by Edwards (1930). The systematic position of the latter should now be *A.* (*Dunnius*) *albomarginatus* subsp. *kummi*.

Eretmapodites sp. indet. A mosquito of this genus, closely allied to *E. dracaenae*, Edw., was recovered in large numbers in Kaimosi, both in the mature form and as larvae from *Dracaena* axils. The larva appears to be indistinguishable from that of *E. dracaenae*. The adult belongs to the *E. quinquevittatus* group and exhibits a most characteristic morphology in the male terminalia. The distal claspette is a huge structure arising from the junction of the coxite and tergite and bearing numerous " hairs " quite unlike any others seen in this genus. The delicate stalk expands into a disc bordered by a fringe resembling that of the comb scales of certain Aëdine larvae. The species will be fully described later by Mrs. Van Someren.

Culex (*C.*) *salisburiensis*. In a number of minor details the larva of this species differs from the published description. These are as follows:—The mentum has one basal tooth followed by four (instead of three) large ones; then the apex. Comb scales number about 70 instead of 40 to 50. With the exception of the most distal one, the basal denticles of the pecten spines number four instead of two and there are 16 spines (type form has 14).

C. (*Culiciomyia*) *subaequalis*. The position of the antennal tuft slightly before $\frac{1}{2}$, the row of prominent spicules on the posterior margin of the anal segment and the shape of the mentum make this larva readily separable from others of the genus. The mentum is rectangular with three well separated distal teeth followed by ten closely packed teeth of which the most distal are longest. A full description will be given by Van Someren.

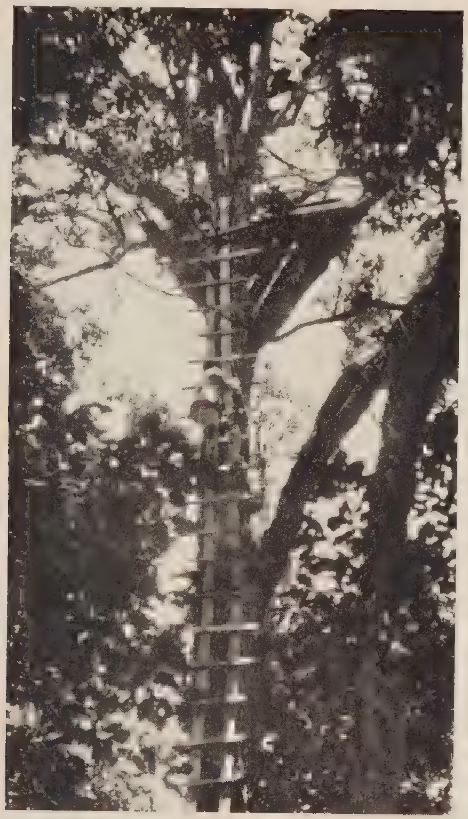

Fig. 1.

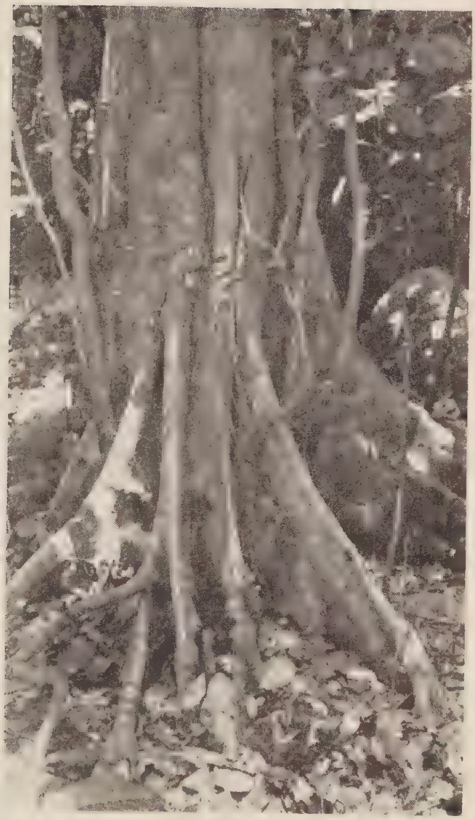

Fig. 2.

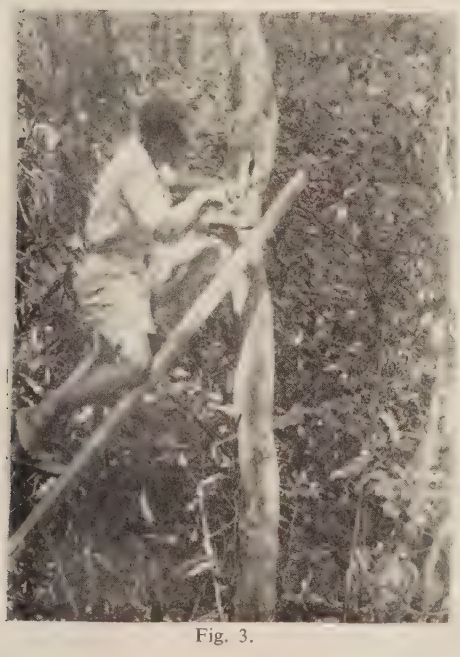

Fig. 3.

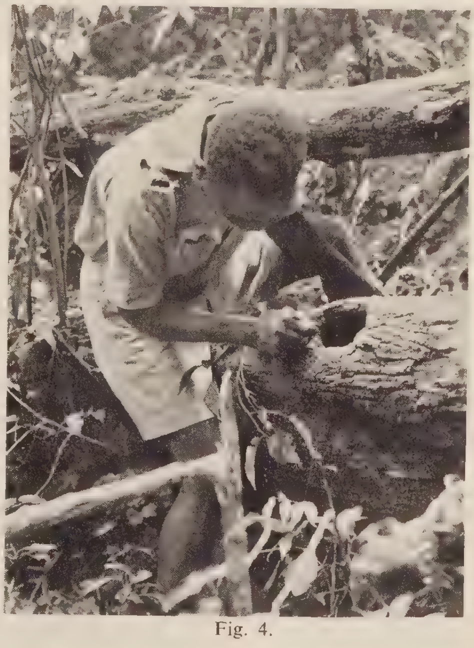

Fig. 4.

Fig. 1. Tree platform and ladder. Height is 55 feet.

Fig. 2. The characteristic breeding place of *A. africanus:* Pool in buttresses of *Craibia elliottii.*

Fig. 3. Tree hole at 18 feet, breeding *A. longipalpis.*

Fig. 4. Hole in fallen tree with water constantly infested with Megarhines, *T. fraseri* and *C. adersianus.*

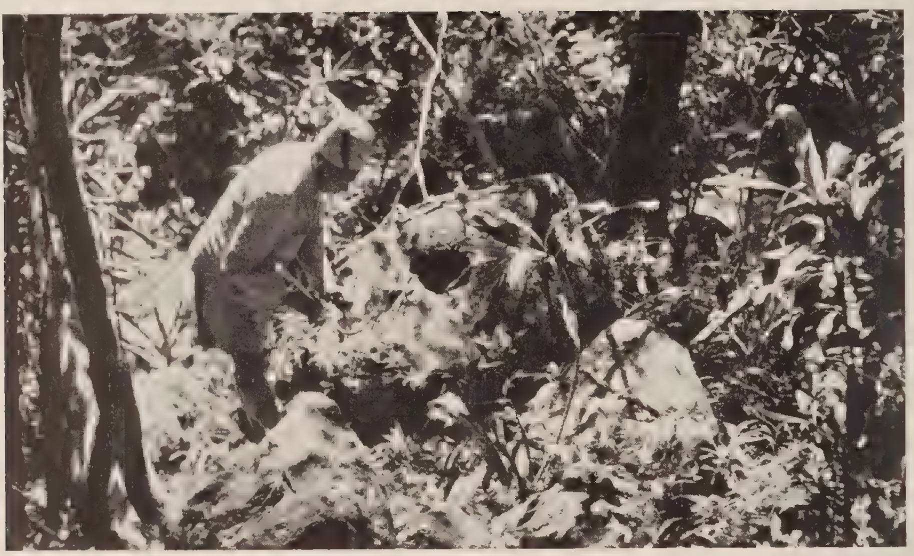

Fig. 1.

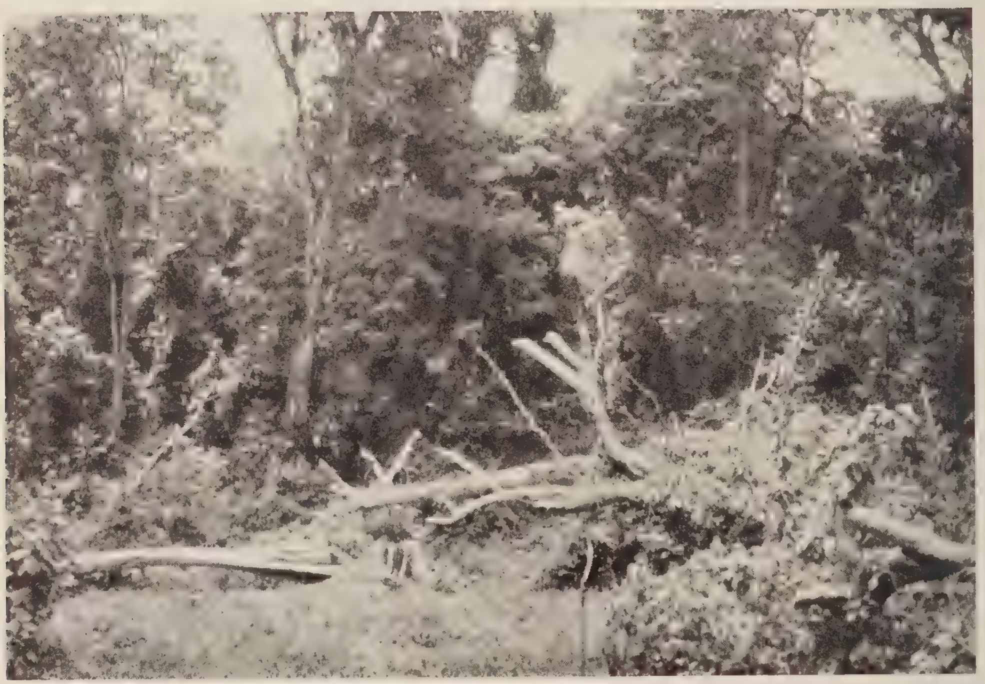

Fig. 2.

Fig. 1. Holes in rock boulders. Favourite breeding place of many sylvan species of mosquitos.

Fig. 2. Felled trees at forest edge. A common breeding place of *A. aegypti*.

THE SANDFLIES OF CYPRUS (DIPTERA).

By S. Adler, O.B.E.

Department of Parasitology, Hebrew University, Jerusalem.

(Plate XVIII.)

Owing to the kindness of Dr. R. L. Cheverton, D.M.S., Cyprus, we had an opportunity of carrying out an investigation into the sandflies of Cyprus between 10th August and 9th September, 1944. Collections were made in various localities in order to obtain, as far as possible, a representative picture of the sandfly population of the island. Sandflies were caught daily between 9 p.m. and 1 a.m. in houses and stables and in their immediate vicinity. Very few specimens were found inside stables possibly because animals are kept in the open during the hot summer nights. Altogether a total of 2,000 specimens were examined and the following species were found.

Phlebotomus papatasii, Scopoli 1786.

This is the commonest species on the island and is ubiquitous. Specimens were caught mainly in and near houses; very few were found in stables but large numbers were caught in a cave near a cowshed.

P. sergenti, Parrot 1917.

Only four specimens were found. Prodromos 2 ♀♀, 1 ♂, Lapithos 1 ♂. The variation in the wing index is very striking. In one ♀ $\frac{\alpha}{\beta} = 1$, in the second $\frac{\alpha}{\beta} = 2$; in one ♂ $\frac{\alpha}{\beta} = 2$ and in the second 1·5.

P. alexandri, Sinton 1928.

Syn. *P. sergenti* var. Newstead 1920; *P. sergenti* var. *alexandri,* Sinton 1928.

Newstead (1920) differentiated this variety from typical *P. sergenti* by its relatively short antennal segments and the inequality of the distal spine-bearing tubercles on the distal segment of the superior clasper in the male. Sinton (1928) proposed the name *P. sergenti* var. *alexandri,* and Parrot (1936) raised it to specific rank. This change in nomenclature is justified, because in addition to the above mentioned differences from *P. sergenti*, there are also striking differences in the pharynx of the females. In *P. sergenti* ♀ the medium rows of teeth are almost vertical, and they become increasingly oblique towards the lateral border of the pharynx. Posteriorly behind the vertical and oblique teeth there is a row of several horizontal ridges. In *P. alexandri* the teeth are smaller than in *P. sergenti,* all oblique except for a very few in the centre of the anterior margin, and the posterior ridges are absent (in one Indian specimen from Sind there is an indication of a single posterior ridge).

Parrot and Biojout (1939) have pointed out that in *P. alexandri* from N. Africa the geniculate spines on the antennae of the female are relatively long, and those on the fourth antennal segment reach or even extend beyond the union of the fourth and fifth segments. This character is also found in our Cyprus material but in a specimen from Sind determined by Sinton the geniculate spines are distinctly shorter.

Material examined: Aghirda 3 ♀♀, 11 ♂♂, Goshi 2 ♂♂, Trimithi 1 ♂, Pedhoulas 1 ♂.

P. perniciosus var. **tobbi,** Adler, Theodor & Lourie 1931.

Material examined: Aghirda 18 ♀♀, 5 ♂♂, Lapithos 1 ♂, Kyrenia 2 ♀♀, Trimithi 5 ♀♀, Kakopetria 1 ♀, Skouriotissa 3 ♀♀, Kambos 3 ♀♀, Chakistra 2 ♂♂, Ktima 7 ♀♀, 7 ♂♂.

This species appears to be the commonest member of the *major* group on the island.

P. chinensis, Newstead 1916.

Syn. *P. major* var. *chinensis,* Newstead 1916.

♀. Size 3·2 to 3·85 mm. (measured after treatment in potash). Palps: 1, 4, (3, 2), 5. The proportions between the segments: segment 4 about two-thirds the length of segment 2; segment 5 about twice the length of 2; segments 2 and 3 sub-equal but 2 may be very slightly bigger than 3. Epipharynx 0·3 to 0·37 mm. Antennae $A_3 > 4 + 5$. $\frac{A}{E}$ varies from 0·8 to 1. Wings 2·2 mm. long with a maximum width of 0·67 mm. Wing index $\frac{\alpha}{\beta} = 1{\cdot}5$ to 1·6. Spermathecae as in typical *P. chinensis*.

♂. Size 3·1 to 3·8 mm. Palps: 1, 4 (2, 3), 5. As in female. Antennae—$3 > 4 + 5$. Epipharynx 0·26 to 0·3 mm. $\frac{A}{E} = 1{\cdot}05$ to 1·2. Male genitalia of the *major* group type and similar to *P. chinensis* except for the tubercle on the penis (fig. 1*b*) which is small, wedge-shaped and subterminal. The genital filaments are 8 to 9 times the length of the pump.

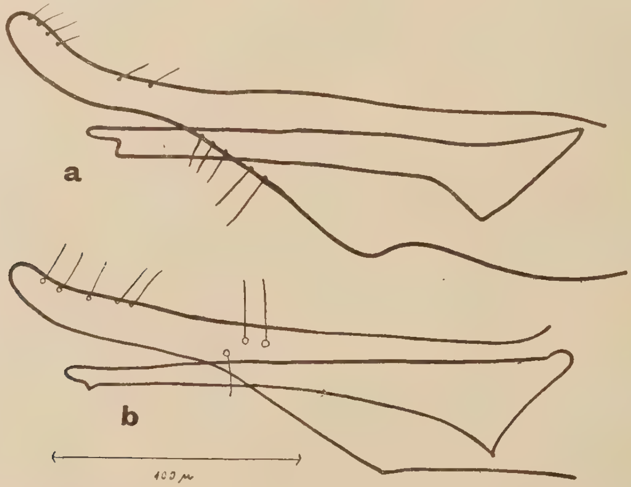

FIG. 1.—Penis and intermediate appendage of: (a) *P. chinensis* from Hamadan; (b) *P. chinensis* from Cyprus.

Adler and Theodor (1929, 1931), Adler, Theodor & Lourie (1931) have pointed out that *P. chinensis* contains a number of races which are distinguished by differences in the distal portion of the penis.

Nitzulescu (1929, 1931 *b*) showed that there are two distinct races in the Balkans. One is characterised by relatively long genital filaments (10 times the length of the pump); the penis is considerably shorter than the intermediate appendage and the subapical tubercle is characteristic. He included this race together with material described by Adler and Theodor (1929, 1931) from Aleppo and Persia, and by Parrot from Bokhara in *P. chinensis* var. *longiductus*. He named the other Balkan race *P. chinensis* var. *simici* (defined by a relatively shorter genital filament, 7 times as long as the pump, by the subapical tubercle, the relatively long penis, which is almost as long as the intermediate appendage, and by the relatively darker teeth in the pharynx of the female). He included material described by Adler and Theodor from Galilee in this variety.

Since *P. chinensis* is the carrier of kala-azar in China, it is important to clarify the morphological characters of the various races described since 1928, because in other groups of sandflies it has been found that slight differences in morphology may be accompanied by profound differences in bionomics and capacity to transmit disease. For example, there are profound differences in the bionomics of *P. sergenti* and *P. caucasicus*, which were once considered as varieties, and they differ in the length of the pedicle of the brush on the superior clasper of the male and slightly in the pharyngeal teeth of the female. The former is by far the more efficient carrier of *Leishmania tropica*.

We agree, on the basis of material collected in Galilee and in Crete, that *P. chinensis* var. *simici* is quite distinct from any other form of *P. chinensis*. Apart from the differences in the male, the character of the female pharynx is distinctive. The toothed area is smaller than in other forms and extends anteriorly up to about one-fifth of the longitudinal axis of the pharynx. In the Chinese, Persian and Syrian forms, the toothed area extends up to a little beyond the posterior third of the longitudinal axis and a little behind this point in the specimens from Cyprus. As Nitzulescu has pointed out, the pharyngeal teeth of *P. chinensis* var. *simici* are darker than those of the other forms. On re-examining our material we found several specimens of *P. chinensis* var. *simici* in material from Kermanshah and Hamadan where it occurs together with a race of *P. chinensis*, with relatively long genital filaments and a terminal notch but without a preterminal tubercle on the penis (fig. 1, *a*).

Parrot (1928) described *P. major* var. *longiductus* from two males from Bokhara. Later the name was emended to *P. chinensis* var. *longiductus* because of the obvious affinity of Parrot's specimen to *P. chinensis*. Parrot's illustrations show a wedge-shaped preterminal tubercle on the penis and genital filaments about 13 times as long as the pump, *i.e.*, much longer than that recorded by Nitzulescu in his material from Rumania.

A re-examination of our material from Aleppo and Hamadan has convinced us that it does not conform to Nitzulescu's description of his Rumanian material. There is no preterminal tubercle but there is a preterminal notch (fig. 1, *a*). The genital filaments are 13-15 times as long as the pump. Material examined from Tiflis showed identical characters.

The name *P. chinensis* var. *longiductus* should, therefore, be restricted to specimens with the character illustrated by Parrot in his original description. Our material from Cyprus differs from the Rumanian in size (according to Nitzulescu 2·8 mm. in the male after treatment in potash), in the relatively shorter genital filaments and in the relative length of the third antennal segment as compared to the epipharynx. $\frac{A}{E}$ in males = 1·8 in the Rumanian form (according to Nitzulescu's figures), 1·5 in *P. chinensis* var. *longiductus* and in the forms from Syria and Persia, 1·7 in *P. chinensis* s. str. and 1·1-1·2 in *P. simici*. The latter character is practically constant in this group of sandflies.

As can be seen from the above brief description of the material examined up to date, there are certainly five and possibly six varieties of *P. chinensis* each with distinct morphological characters in the male. Relatively little is known of the bionomics of the above races apart from *P. chinensis* s. str. and *P. c.* var. *simici* which differ profoundly in their seasonal distribution. *P. chinensis* is abundant from the end of May till the beginning of July and apparently has only one annual generation. *P. chinensis* var. *simici* is common all through the sandfly season from the middle of May till the beginning or middle of November.

Material examined: Aghirda 2 ♀♀, 3 ♂♂, Trimithi, 2 ♀♀, 6 ♂♂, Lapithos 2 ♀♀, 1 ♂, Kyrenia 1 ♀, Bella Paise 1 ♀. All these localities are in the Kyrenia Range.*

P. perfiliewi, Parrot 1930 **and closely related Species.**

Syn. *P. macedonicus,* Adler & Theodor 1930.

No examples were found among the 2,000 specimens examined in Cyprus but a single female occurred in a breeding pot into which wild females caught in Kyrenia were introduced. This female laid eggs which hatched and developed in the laboratory in Jerusalem. This species is apparently rare in Cyprus.

P. perfiliewi is zoophilic, and in localities where it is abundant it is associated with a high incidence of visceral leishmaniasis in dogs and a very low one in man. A striking example of this is found in the Valley of Jezreel where *P. perfiliewi* is common and is the only sandfly of the *major* group found up to date. Canine kala-azar is very common, and we found five out of five dogs infected in the village of Merhaviah, but only two human cases are known to have occurred throughout the whole valley in the past 20 years (one in Nahalal and one in Affuleh).

The male of this species can be readily distinguished by the shape of the penis, but the females are very similar to those of *P. perniciosus, P. p.* var. *tobbi* and *P. major* var. *syriacus. P. perniciosus* and *P. p.* var. *tobbi* have no known common areas of distribution but one race of *P. major* is found together with *P. perniciosus* and *P. perfiliewi* in Gozo, Malta, another distinct race of *P. major* is found together with *P. perfiliewi* and *P. perniciosus* var. *tobbi* in the Balkans, and *P. major* var. *syriacus* is found together with *P. perniciosus* var. *tobbi* and *P. perfiliewi* in Palestine. In all these species the pharynx and spermathecae are of one type and differ only in minute details. Since carriers of kala-azar in the Mediterranean occur among the above species, it is obviously a matter of fundamental importance to attempt a differential diagnosis between the very similar females of closely related species with an overlapping distribution.

In the case of preserved material, differential diagnosis is possible only on the basis of minute differences in the pharyngeal teeth, in the relative length of the third antennal segment and (in the case of *P. perfiliewi*) the terminal part of the common salivary duct. In Italy *P. perniciosus* and *P. major* can be distinguished in fresh dissections by the character of the granules of the accessory glands (Adler & Theodor, 1931).

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* With the exception of *P. chinensis* s. str., which has been the subject of extensive investigations in kala-azar studies in China, relatively little work has been done on the other forms of *P. chinensis*. *P. chinensis* var. *simici* has been infected in the laboratory (Adler & Theodor, 1935) with *Leishmania donovani* (Indian strain) and *L. infantum* (Catania and Maltese strains). In October 1939 we fed *P. chinensis* var. *simici* on a Syrian hamster heavily infected with a Brazilian strain of *L. chagasi*. Nine sandflies fed and were dissected four days later. Five sandflies were found to be infected; in all of them the infection was slight, flagellates were found in the stomach of two only and in the other three they had ascended to the middle of the cardia. We had no further opportunity of continuing this work. Nothing whatever is known about the other races of *P. chinensis* as potential carriers of leishmaniasis.

In *P. major*, as in other members of the genus, there are, as Adler & Theodor (1931) have indicated, distinct geographical "races" differing among themselves in minute morphological details. As these differences, though very slight, are constant, these races will eventually have to be recognised as varieties. Adler & Theodor (1931) named the forms found in Syria and Palestine *P. major* var. *syriacus*, because the females are readily distinguished from the Italian and Indian forms. They are also readily distinguished from the Balkan forms. In var. *syriacus* the pharyngeal armature (fig. 2*a*) extends in the medium line for about 30 per cent. of the length of the longitudinal axis of the pharynx. The most anterior teeth are scale-like in contrast to those behind them which appear as points in optical section. The index $\frac{A}{E}$ varies from 0·9 to 1. The male is readily distinguished from that of the other known races by the index $\frac{A}{E}$ which varies from 1·4 to 1·5. No other Mediterranean race of this species has such a high index in the male.

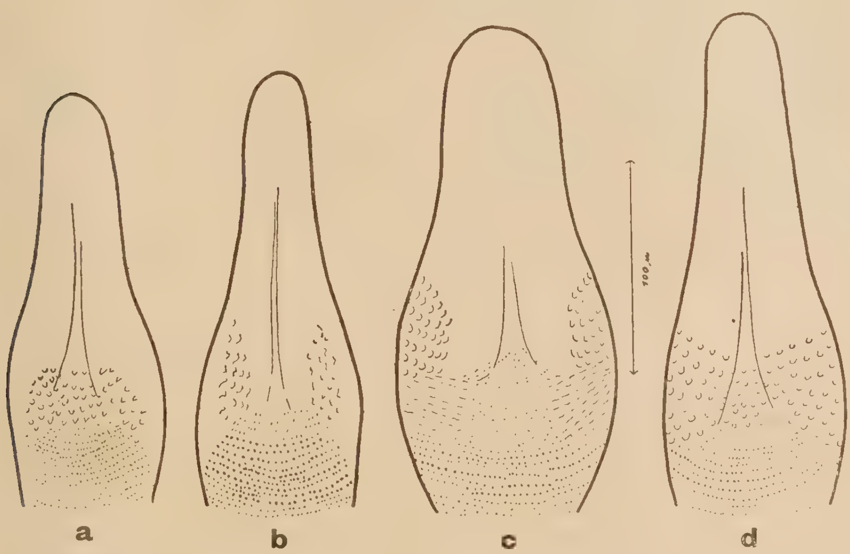

FIG. 2.—Pharynx of ♀: (a) *P. major* var. *syriacus*; (b) *P. major* from Crete; (c) *P. major* from Italy; (d) *P. major* from India.

In the Greek specimens collected in Athens and Crete, the teeth extend for about 25 per cent. of the longitudinal axis of the pharynx medially but the lateral teeth extend to almost half way between the anterior and posterior ends of the pharynx (fig. 2*b*). Medially the anterior teeth appear as points or short vertical lines, laterally as scales. The index $\frac{A}{E}$ is 0·8 in the female and this distinguishes it from all the other known races. In the male the index varies from 1·2 to 1·3.

In the Italian race the pharynx is similar to that of the Balkan form but the median anterior teeth which appear as points extend further anteriorly along the axis of the pharynx than in the Balkan forms (fig. 2*c*). The lateral teeth are scale-like and extend to about half way between the anterior and posterior ends of the pharynx. The female is readily distinguished from the Balkan form by the index $\frac{A}{E}$ which varies from 0·9 to 1·0, and from *P. major* var. *syriacus* by the pharyngeal armature.

The Indian race differs from the others in details of the pharynx. The most anterior median teeth are scale-like (fig. 2*d*). Laterally the teeth extend to rather less than half the length of the pharynx. In the female $\frac{A}{E} = 0 \cdot 9$.

In addition to these morphological differences there are also differences in bionomics among the Mediterranean races of *P. major*. Thus in the Italian forms, in contrast to the others, the unfed female is markedly phototropic. We noticed an interesting biological difference between the Balkan race of *P. major* and *P. m.* var. *syriacus*. The former feeds readily on Syrian hamsters and digests the blood to a syrupy mass; the ova grow and develop yolk granules but do not become mature. *P. major* var. *syriacus* will not feed at all on Syrian hamsters in an open cage but can be made to feed on these animals in Hertig's feeding box. During October, 1944, numerous specimens of *P. major* var. *syriacus* were fed on Syrian hamsters; none digested the blood meal, unaltered red corpuscles were found in the stomach after three days and the ova did not grow or develop yolk granules. Wild females which fed at the same time on human beings digested the blood meal and developed mature ova. Laboratory bred females from Upper Galilee fed on Syrian hamsters during December, 1944, did not digest the blood meal even after three days at 30°C. and the ova did not develop yolk granules.

The above differences in geographical races, varieties or species (according to the taste of the individual investigator) are interesting in themselves and in the case of *P. major* they may prove to be important in the epidemiology of visceral leishmaniasis. Thus there is as yet no evidence for associating *P. major* with visceral leishmaniasis in India, whereas in Sicily it has a higher infection rate when fed on infected dogs than even *P. perniciosus* (Adler & Theodor, 1935) and in Crete the local race of *P. major* is the only carrier of the disease in the island.

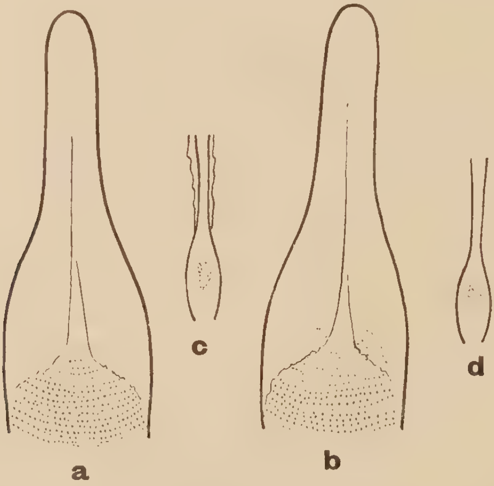

FIG. 3.—Pharynx of ♀♀: (a) *P. perfiliewi*; (b) *P. perniciosus*. Salivary pump and termination of common salivary duct of ♀♀: (c) *P. perfiliewi*; (d) *P. perniciosus*.

P. perniciosus can be distinguished from *P. perfiliewi* by minute differences in the pharyngeal teeth. In *P. perfiliewi* the teeth extend anteriorly as far as the posterior margin of the inferior lateral plates of the pharynx (fig. 3*a*); in specimens of *P. perniciosus* thoroughly cleared in potash very small point-like teeth are found anterior to these margins (fig. 3*b*). In specimens mounted with the head horizontal, the part of the common salivary duct which lies under the floor of the buccal cavity can be clearly seen up to its entrance into the salivary pump. The wall of the common salivary duct in *P. perfiliewi* (fig. 3*c*) is considerably thicker than in *P. perniciosus* (fig. 3*d*). In *P. perfiliewi* $\frac{A}{E} = 0{\cdot}9$, in *P. perniciosus* 0·9 to 1.

So far as Cyprus is concerned, it is necessary to distinguish between the females of *P. perfiliewi* and *P. perniciosus* var. *tobbi*. The only constant differences we could find are that in the former $\frac{A}{E} = 0{\cdot}9$ and in the latter 0·8; the wall of the common salivary duct is thicker in the former than in the latter.

In *P. major* var. *syriacus* $\frac{A}{E}$ varies from 0·9 to 0·1. The anterior median teeth of the pharynx are faint and scale-like in contrast to those of *P. perfiliewi*, *P. perniciosus* and *P. p.* var. *tobbi*, which appear in optical section as fine points or very short vertical or oblique lines.

Actually the taxonomic differences between the females of *P. perniciosus*, *P. p.* var. *tobbi*, *P. perfiliewi* and *P. major* var. *syriacus* are considerably less than those found among the females of the various races of *P. major*. In *P. major* different races have diverged in the details of the pharyngeal armature in both sexes while the male genitalia have remained constant; in *P. major* var. *syriacus* and the other three sandflies there are striking differences in the male genitalia (*i.e.*, the shape of the penis) which are of prime diagnostic importance while the females are so similar that but for the glaring differences in the males they would hardly be suspected even of being varieties of a single species.

P. larroussei, Langeron & Nitzulescu 1931.

A single male was caught in Aghirda on 22.viii.44. This rare species has been recorded from France, Naples and Crete always in small numbers. Only two males have so far been recorded as described in the literature, one from France by Parrot (an incomplete specimen) and one from Crete by Adler, Theodor & Witenberg, 1938. Our specimen from Aghirda corresponds in all essential details to the description of the latter authors.

P. fallax var. **cypriotica,** var. nov.

Parrot (1921) described *P. minutus* var. *fallax* and later (1921*a*) elevated it to specific rank because the external male genitalia were relatively narrow as compared with *P. minutus* and because of the alleged absence of the accessory seta on the distal segment of the superior clasper. Nitzulescu (1931*a*) rightly pointed out that the accessory seta is present but is very short and thin. After examining a cotype and material from Tunis he concluded that there were not sufficient grounds for giving it specific rank and re-instated it as a variety. On the other hand, neither Parrot nor Nitzulescu had the opportunity of examining females, whereas our material contains ample specimens of both sexes, and it is now regarded as a new and distinct variety of *P. fallax*, which is the commonest species of the *minutus* group in Cyprus.

♀. Size: 1·7 to 2·3 mm. (after treatment in potash). Palps: 1, 2 (3, 4), 5. Segment 3 may be equal or slightly longer or shorter than segment 4. Segment 5 is rather more than twice as long as segment 4. Antennae: $3 < 4 + 5$. Epipharynx: 0·1 to 0·13 mm. $\frac{A}{E} = 0{\cdot}75$ to 0·85. Wings: 1·3 to 1·5 mm. long with a maximum breadth of 0·3 to 0·4. $\frac{\alpha}{\beta}$ varies from 0·5 to 0·7.

Buccal cavity (figs. 4*a* and *b*). There are 16 to 18 teeth almost equal in size standing on an arc convex anteriorly. The pigmented area is elliptical. Pharynx (fig. 4*b* and Plate XVIII, fig. 1): markedly widened posteriorly. Length over maximum breadth = 2 : 1. The toothed area is triangular with the apex anterior. The posterior part of the toothed area contains innumerable fine teeth which appear as points in optical section. The anterior teeth are fewer and much larger. The posterior margin of the toothed area is indented. The character of the pharynx readily distinguishes this species from any other member of the *minutus* group. Spermathecae: tubular and of the *minutus* type.

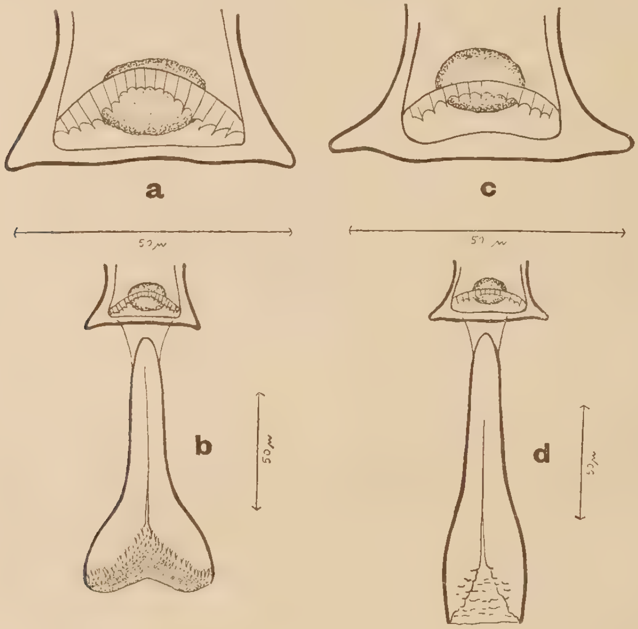

FIG. 4.—*P. fallax cypriotica*, var. nov. (*a*) Buccal cavity of ♀; (*b*) pharynx and buccal cavity of ♀; (*c*) buccal cavity of ♂; (*d*) pharynx and buccal cavity of ♂.

♂. Size: 2·1 mm. to 2·4 mm. Palps: 1, 2 (3, 4), 5. Variations as in female. Antennae: $3 < 4+5$. Epipharynx: 0·12 mm. $\frac{A}{E}=0{\cdot}9$ to 1. Wings: Length 1·4 to 1·5 mm., maximum breadth 0·3 to 0·33 mm. The wing index is variable $\frac{\alpha}{\beta}=0{\cdot}3$ to 0·64.

Buccal cavity (fig. 4*c*). Twelve teeth stand on an arc convex anteriorly. (Nitzulescu figured 15 teeth in a Tunisian specimen.) The pigmented area when present is elliptical, much smaller and fainter than in the female. In some specimens it is absent. Pharynx (fig. 4*d*): Length over maximum breadth = 3·5 : 1, teeth hardly evident.

Genitalia (fig. 5*a*): of the *minutus* type; four terminal spines and one very short and thin subterminal seta. The superior clasper is relatively thicker than in the type, *i.e.*, 3·5 to 4·5 longer than wide in the Cyprus specimens and 5·6 to 7 times in 2 specimens obtained from Dr. L. Parrot. In the Algerian specimens the proximal segment of the superior clasper is 2·2 times as long as the distal segment, in the Cyprus material 2·5 to 3 times as long.

The males from Cyprus thus show slight differences from the North African forms in the buccal cavity and genitalia. The female of *P. fallax* from Tunis and Algeria is unknown.

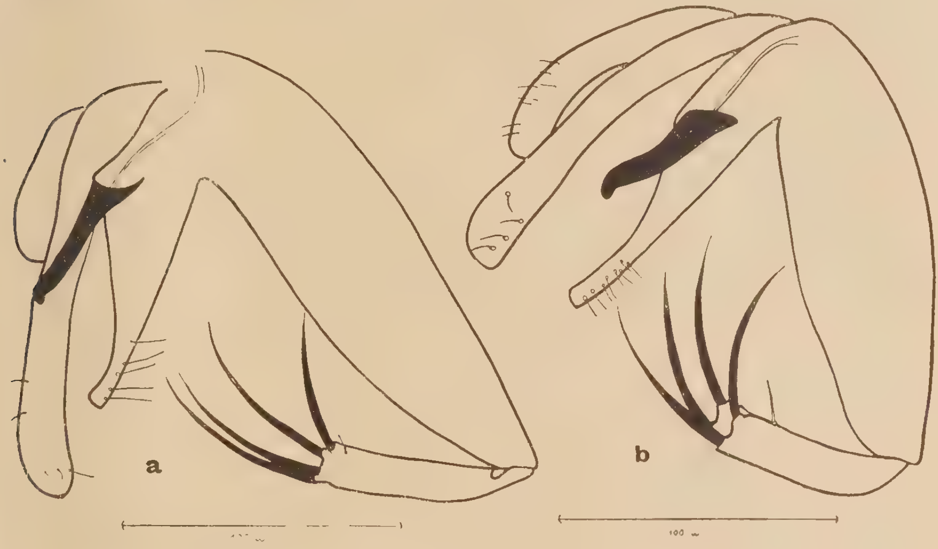

FIG. 5.—(*a*) Male genitalia of: (*a*) *P. fallax cypriotica*, var. nov.; (*b*) *P. azizi*.

Material examined: Aghirda 7 ♀♀, 22 ♂♂, Bella Paise 2 ♀♀, 3 ♂♂, Myrtou 1 ♂, Trimithi 12 ♀♀, 14 ♂♂, Ayios Giorgios 6 ♀♀, Nicosia 4 ♀♀, 6 ♂♂, Lapithos 3 ♀♀, 1 ♂, Kyrenia 4 ♀♀, 13 ♂♂, Skouriotissa 5 ♂♂, Yialoussa 9 ♂♂, Ktima 8 ♀♀, 2 ♂♂.*

P. azizi, sp. n.

♀. Size: 2 to 2·6 mm. (specimens treated in potash). Palps: 1, 2 (3, 4), 5; segment 3 may be equal, slightly longer or shorter than 4; segment 5 is about twice the length of 4. Antennae: $3 < 4+5$. Epipharynx: 0·13 to 0·15 mm. $\frac{A}{E} = 0{\cdot}6$. Wings: 1·4 to 1·7 mm. long, maximum breadth 0·3 to 0·4 mm. Wing index: $\frac{\alpha}{\beta}$ varies from 0·44 to 0·7.

Buccal cavity (fig. 6*a*) contains 30 teeth standing on an arc convex anteriorly. The teeth have sharp points and the median teeth are smaller and narrower than the lateral ones. The pigmented area has the form of a large segment of a circle with the chord posterior. Pharynx (fig. 6*b* and Plate XVIII, fig. 2). Length over maximum breadth = 8 : 3. The teeth are strongly marked and approximately uniform in type in striking contrast to *P. fallax* var. *cypriotica*. The posterior margin of the toothed area is not indented anteriorly. The shape of the pharynx and the dentition is rather like that of *P. bruchoni*, Parrot 1935. Spermathecae: Tubular of *minutus* type.

♂. Size 2·1 to 2·8 mm. (specimens mounted in potash). Palps: 1, 2 (3, 4), 5, with variations as in female. Antennae: $4 < 3+5$. Epipharynx: 0·12 to 0·14 mm. $\frac{A}{E} = 0{\cdot}8$ to 0·9. Wings: 1·3 to 1·8 mm. long with a maximum breadth of 0·3 to 0·4 mm. Wing index: $\frac{\alpha}{\beta}$ varies from 0·4 to 0·6.

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* One female was found in Rosh-Pina in Upper Galilee.

Buccal cavity (fig. 6*c*) contains 18 to 20 teeth standing on an arc convex anteriorly. The teeth are smaller than in the female. The pigmented area is elliptical, smaller and fainter than in the female. Pharynx (fig. 6*d*). Length over maximum breadth = 3, 2:1. The teeth are reduced to a few horizontal ridges.

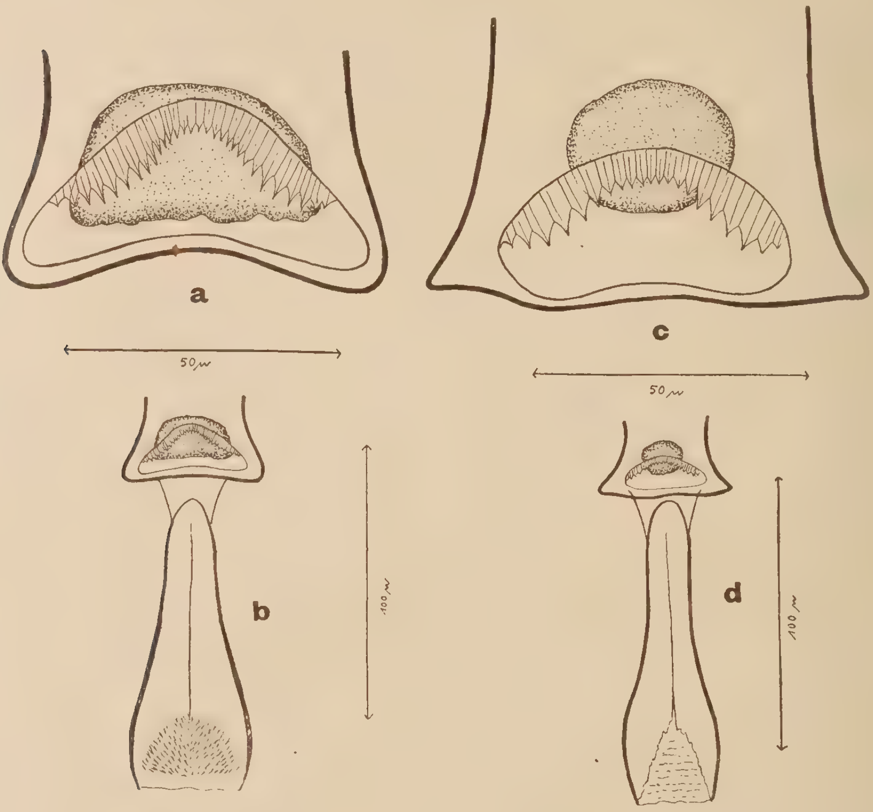

FIG. 6.—*P. azizi*, sp. n. (*a*) buccal cavity of ♀; (*b*) pharynx and buccal cavity of ♀; (*c*) buccal cavity of ♂; (*d*) pharynx and buccal cavity of ♂.

Genitalia (fig. 5*b*) of the *minutus* type. The distal segment of the superior clasper bears 4 terminal spines and a strongly marked seta placed at the junction of the lowest and third quarters of the segment. The intermediate appendage terminates posteriorly a little in front of the termination of the inferior clasper (in *P. fallax* it is considerably shorter and terminates about the level of the junction of the posterior third and fourth quarters of the inferior clasper).

This new species belongs to a group of closely related species which includes *P. schoutedeni*, Adler, Theodor & Parrot 1929; *P. congolensis*, Bequaert & Walravens 1930; *P. yusafi*, Sinton 1930; *P. bruchoni*, Parrot 1935 and *P. minutus* var. *arpaklensis*, Perfiliew 1933. In all these species, in spite of minor specific difference, the pharynx is of the same type; it is roughly lamp-glass shaped, the teeth are uniform in type and the posterior margin of the toothed area is not indented. As *P. minutus* var. *arpaklensis* shows these characters, it cannot therefore be considered as a variety of *P. minutus* and should be elevated to specific rank. The above species differ among each other in minor characters and in the number of teeth in the buccal cavity of the female; 16-18 in *P. bruchoni,* 40 in *P. congolensis* according to Theodor, 25 in *P. yusafi* according to Sinton, 30 in *P. azizi,* 18-20 in *P. arpaklensis* according to Perfiliew, 10 to 16 according to Theodor (it is probable that Theodor and Perfiliew were not dealing with the same species because the number of teeth in the buccal cavity is fairly constant and such a wide range of variation, 10 to 20, in the female is unknown in any member of the *minutus* group). It is difficult to decide whether to consider them all as varieties of one species, *i.e.,* of *P. schoutedeni,* or as distinct species. The tendency has been to consider them as distinct species. We dedicate *P. azizi* to Mr. Mehmed Aziz of the Department of Health of Cyprus.

Theodor (1933) in a study of *P. minutus* has shown that specimens from different regions differ in the number of teeth in the buccal cavity and he differentiated varieties on this character. A review of the whole *minutus* group shows that differences between closely related species naturally revolve round this character and this is clearly seen in the group of sandflies for which *P. schoutedeni* may serve as a type.

Material examined: Kyrenia 2 ♀♀, 8 ♂♂, Skouriotissa 5 ♀♀, Trimithi 2 ♀♀, 7 ♂♂, Ghaziveran 1 ♀, 3 ♂♂, Ayios Giorgios 3 ♀♀, Pedhoulas 1 ♀, Rhizokarpaso 1 ♀, Goshi 1 ♀.

P. parroti, Adler & Theodor 1927.

This name was originally applied to a sandfly from Algeria characterised by a buccal cavity containing 70 to 80 teeth standing in a horizontal row. In Italy, the Balkans and Crete it is replaced by a variety containing about 50 teeth in the buccal cavity *P. parroti* var. *italicus,* Adler & Theodor 1931. It was therefore rather surprising to find *P. parroti* in Cyprus with 80-90 teeth in the buccal cavity of the female.

Three specimens caught at Pedhoulas were melanic. In the female melanism was accompanied with a marked reduction of the teeth in the pharynx as compared to the normal (Plate XVIII, figs. 3 and 4). Our material is too scanty to determine whether reduction in the pharyngeal teeth is constantly associated with melanism.

Material examined: Skouriotissa 4 ♂♂, Lapithos 1 ♂, Trimithi 1 ♀, 1 ♂, Kakopetria 1 ♀, 5 ♂♂, Nicosia 1 ♀, Pedhoulas 2 ♀♀, 1 ♂, Aghirda 1 ♀, 7 ♂♂, Kormakiti 1 ♂, Ktima 7 ♂♂.

KEY TO SANDFLIES OF CYPRUS.

Males.

1.	(*a*)	Distal segment of superior clasper bears 5 spines	2
	(*b*)	Distal segment of superior clasper bears 4 spines	4
2.	(*a*)	Three short spines terminal and two median	*P. papatasii*
	(*b*)	Two long spines terminal and three median	3
3.	(*a*)	Extremity of penis bifid with two unequal terminal processes	*P. perniciosus* var. *tobbi*
	(*b*)	Penis tapers towards extremity which is rounded	*P. larroussei*
	(*c*)	Penis terminates in a long curved hook bearing several serrations near distal end and genital filaments emerge at commencement of distal third of penis	*P. perfiliewi*
	(*d*)	Small subterminal tubercle on penis. Genital filaments emerge from tip	*P. chinensis*
4.	(*a*)	Two long spines terminal and two median	5
	(*b*)	All four spines terminal	6

5. (*a*) Processes bearing the two terminal spines are markedly unequal; the third antennal segment is much shorter than the epipharynx ... ... *P. alexandri*
(*b*) Processes bearing two terminal spines are not markedly unequal; third antennal segment approximately as long as epipharynx ... ... *P. sergenti*

6. (*a*) Seta on distal segment of superior clasper long and situated near junction of lower and middle thirds ... ... *P. parroti*
(*b*) Seta on distal segment of superior clasper very short and subterminal ... ... *P. fallax* var. *cypriotica*, nov.
(*c*) Seta on distal segment of superior clasper situated between lower two quarters of segment. Longer and thicker than in *P. fallax* var. *cypriotica* ... ... *P. azizi*, sp. n.

Females.

1. (*a*) No armature in buccal cavity 2
(*b*) Well marked armature in buccal cavity 5

2. (*a*) Pharyngeal teeth appear as parallel rows of points. Spermathecae segmented with long proximal neck-like process 3
(*b*) Pharyngeal teeth do not appear as points 4

3. (*a*) $\frac{A}{E} = 0{\cdot}8$. Wall of common salivary duct thin ... ... *P. perniciosus* var. *tobbi*

(*b*) $\frac{A}{E} = 0{\cdot}9$. Wall of common salivary duct relatively thick *P. perfiliewi*

4. (*a*) Pharyngeal teeth appear as network of irregular flat scales. Spermathecae completely segmented without long neck-like process ... ... *P. papatasii*
(*b*) Teeth in mid part of toothed area parallel to long axis of pharynx. Upper segment of spermathecae longer than others. 3rd antennal segment almost as long as epipharynx ... ... *P. sergenti*
(*c*) Pharyngeal teeth wedge shaped and oblique to long axis of pharynx. Upper segment of spermathecae longer than others. 3rd antennal segment much shorter than epipharynx ($\frac{A}{E} = 0{\cdot}5$) ... ... *P. alexandri*
(*d*) Toothed area in pharynx approximately triangular. Teeth wedge shaped. Spermathecae fusiform, incompletely segmented with a short projection at proximal end ... *P. chinensis*
(*e*) Anterior part of toothed area roughly triangular but sides rounded. Teeth appear as network of scales. Spermathecae fusiform incompletely segmented with a short projection at proximal end ... ... *P. larroussei*

5. (*a*) Teeth in buccal cavity stand on a straight line. Pigmented area elongated horizontally. Pharynx with relatively few teeth ... ... *P. parroti*
(*b*) Teeth in buccal cavity stand on arc convex anteriorly ... 4

6. (*a*) Teeth in buccal cavity 28-32. Toothed area of pharynx not indented posteriorly ... ... *P. azizi*, sp. n.
(*b*) Teeth in buccal cavity 16-20. Toothed area of pharynx indented posteriorly ... ... *P. fallax* var. *cypriotica*, nov.

General Remarks.

The sandfly fauna of Cyprus shows interesting differences from that of other regions of the Near and Middle East hitherto investigated.

It differs from the Balkans and the Aegean Islands in the following details:—

(1) *P. major* which is common in the Balkans and Crete where it is the main carrier of kala-azar was not found. As this sandfly enters houses very frequently, it could hardly have been overlooked.

(2) *P. chinensis* var. *simici* which is common in the Balkans and Crete was not found.

(3) The commonest member of the *minutus* group is *P. fallax* var. *cypriotica,* which has not been found in the Balkans.

(4) *P. bruchoni* which is present in the Peloponnesus and the Aegean Islands is replaced by the closely allied but distinct *P. azizi.*

(5) *P. parroti* var. *italicus* which is common in Malta, Italy and Crete is not found and is replaced by a form of *P. parroti* nearer to the type as found in Algeria and Tunis.

It differs from Palestine and Syria in the following respects:—

(*a*) There are no members of the *minutus* group common to both regions except *P. fallax* var. *cypriotica* which we have recently found in Upper Galilee.

(*b*) *P. major* var. *syriacus* is common in Palestine and Syria, but was not found in Cyprus.

(*c*) *P. chinensis* var. *simici* which is common in Galilee was not found in Cyprus. The race of *P. chinensis* found in Syria differs from the form present in Cyprus. The latter is quite distinct from any so far recorded elsewhere.

It is not yet possible to compare the sandfly population of Cyprus with that of Anatolia which still awaits a detailed investigation.

Although 4 per cent. of the sandflies entering houses in Cyprus belong to the *major* group, *i.e., P. perniciosus* var. *tobbi* and *P. chinensis,* the population of this group is relatively scanty as compared to Crete, Sicily and Malta. During a whole month of intensive collecting we found only 61 specimens of *P. perniciosus* var. *tobbi* and 18 of *P. chinensis,* whereas 100 to 200 unfed females of *P. perniciosus* can be collected on any still evening in Malta during August and September.*

Leishmaniasis and Sandflies in Cyprus.

Human visceral leishmaniasis has been known on the island since 1935 when Astreos recorded the first case. As the disease is not notifiable, its actual incidence is not known. Mr. R. J. Roe, chief veterinary officer, informed us that he had seen clinical evidence (confirmed by microscopic findings) of canine kala-azar in the island. A hasty examination convinced us that the disease is not rare in dogs. We found 1 out of 19 dogs infected in Nicosia, 1 out of 4 in Karravas, 1 out of 5 in Lapithos, 1 out of 5 in Bella Paise (the last four places are all in the Kyrenia ridge from which the majority of the human cases have been recorded). In all cases the diagnosis was established by spleen smears. The actual incidence is probably less than the above figures indicate because the animals examined were largely selected on the basis of their general appearance. In one of the animals the skin infection was so heavy that *one* out of 15 *P. papatasii* became infected after feeding, the infection being confined to the stomach. *P. papatasii* occasionally becomes infected after feeding on animals with a very heavy skin infection of *Leishmania infantum.*

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* Owing to the short time at our disposal we could not investigate the seasonal incidence of the various species, a point of major importance in the epidemiology of kala-azar. In the Mediterranean basin the population of the *major* group attains its maximum in October.

It is quite obvious that the disease is not of recent origin on the island because, according to Mr. Roe, no animals have been imported from endemic centres for at least thirty years. One of the striking characters of Mediterranean kala-azar is its almost constant annual incidence in man and dog in all endemic centres, and we therefore conclude that the disease has been present in the island for a long time.

The only two species that can be considered as the probable carriers of kala-azar are *P. perniciosus* var. *tobbi* and the local race of *P. chinensis*. The former has been infected with *L. infantum* by feeding on cultures (Adler, Theodor & Lourie, 1930), and on infected hamsters (Adler & Theodor, 1935). *P. perfiliewi* and *P. larroussei* appear to be too rare to be significant as a carrier of disease on the island.

Summary and Conclusions.

The sandflies of Cyprus have been examined. The following ten species were found: *P. papatasii, P. perniciosus* var. *tobbi, P. chinensis* (a local race), *P. perfiliewi* (rare), *P. sergenti, P. alexandri, P. larroussei* (rare). *P. fallax cypriotica,* var. n., *P. azizi,* sp. n., and *P. parroti.*

Melanic forms of *P. parroti* were found. Melanism was associated with a reduction in the teeth of the pharynx in the female in the few specimens collected.

The race of *P. chinensis* found on the island differs from those hitherto described.

The general composition of the sandfly population of Cyprus is different from that of any other part of the Mediterranean examined.

P. major which is common in Palestine, Syria and the Balkans was not found.

Canine kala-azar is common on the island. *P. perniciosus* var. *tobbi* and a race of *P. chinensis* should be considered as possible carriers but this point must be determined experimentally.

Acknowledgements.

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References.

Adler, S. & Theodor, O. (1929). The distribution of sandflies in Palestine, Syria and Mesopotamia.—Ann. trop. Med. Parasit., **22,** pp. 269-306.

——. (1931). Investigations on Mediterranean Kala Azar. III. The sandflies of the Mediterranean basin. Distribution and bionomics of sandflies in Catania and district.—Proc. roy. Soc., (B), **108,** pp. 464-480.

——. (1935). Investigations on Mediterranean Kala Azar. IX. Feeding experiments with *Phlebotomus perniciosus* and other species on animals infected with *Leishmania infantum.*—Proc. roy. Soc., (B) **116,** pp. 516-542.

——, —— & Lourie, E. M. (1931). On sandflies from Persia and Palestine.—Bull. ent. Res., **21,** pp. 529-539.

——. —— & Parrot, L. (1929). Phlébotomes du Congo Belge.—Rev. Zool. Bot. Afr., **18** (2), pp. 1-18.

Astreos, T. C. (1933). Leishmaniasis (Kala-azar).—Annu. med. sanit. Rep. Cyprus, 1935, pp. 84-86.

BEQUAERT, M. & WALRAVENS, P. (1930). Phlébotomes du Katanga.—Rev. Zool. Bot. afr., **19,** pp. 34-42.

NEWSTEAD, R. (1920). On the genus *Phlebotomus*, Part IV.—Bull. ent. Res., **11,** pp. 305-311.

NITZULESCU, V. (1929*a*). Contribution à l'étude des phlébotomes de Roumanie.—Ann. Parasit. hum. comp., **7,** pp. 430-437.

——. (1929*b*). Sur quelques phlébotomes de Yougoslavie.—*T.c.*, pp. 494-505.

——. (1930). Sur le *Phlebotomus chinensis*.—*Op. cit.*, **8,** pp. 362-375.

——. (1931*a*). Deuxième contribution à l'étude des *Phlebotomus* du groupe *minutus*. *Phlebotomus fallax* Parrot 1921.—*Op. cit.*, **9,** pp. 256-260.

——. (1931*b*). A propos du *Phlebotomus chinensis*.—*T.c.*, pp. 261-265.

PARROT, L. (1921). Sur une variété nouvelle de *Phlebotomus minutus*, Rondani.—Bull. Soc. Hist. nat. Afr. N., **12,** pp. 37-40.

——. (1921*a*). Sur l'armature génitale des phlébotomes du groupe *minutus*, Rondani et sur *Phlebotomus fallax*, nov. sp.—Arch. Inst. Pasteur Afr. N., **1,** pp. 99-101.

——. (1928). Notes sur les phlébotomes. II. Sur quelques phlébotomes de la Bokhara (U.R.S.S.).—Arch. Inst. Pasteur Algér., **6,** pp. 26-34.

——. (1935). Notes sur les phlébotomes. XIV. Phlébotomes de Grèce.—*Op. cit.*, **13,** pp. 249-256.

——. (1936). Notes sur les phlébotomes. XXIII. Présence dans l'Aurès (Algérie) de *Phlebotomus sergenti* var. *alexandri* Sinton.—*Op. cit.*, **14,** pp. 428-431.

—— & BIOJOUT, R. (1939). Notes sur les phlébotomes. XXIX. Sur la présence de *Phlebotomus alexandri* Sinton dans le Sahara septentrional.—Arch. Inst. Pasteur Algér., **17,** pp. 233-234.

PERFIL'EV, P. (1933). Ueber neue Stechmücken aus Mittelasien (Turkmenistan).—Zool. Anz., **101,** pp. 221-227.

SINTON, J. A. (1928). The synonymy of the Asiatic species of *Phlebotomus*.—Indian J. med. Res., **16,** pp. 297-324.

——. (1930). Some new species and records of *Phlebotomus* from Africa.—*Op. cit.*, **18,** pp. 171-193.

THEODOR, O. (1931). On African Sandflies (Dipt.).—Bull. ent. Res., **12,** pp. 469-478.

——. (1933). Some African Sandflies.—*Op. cit.*, **24,** pp. 537-547.

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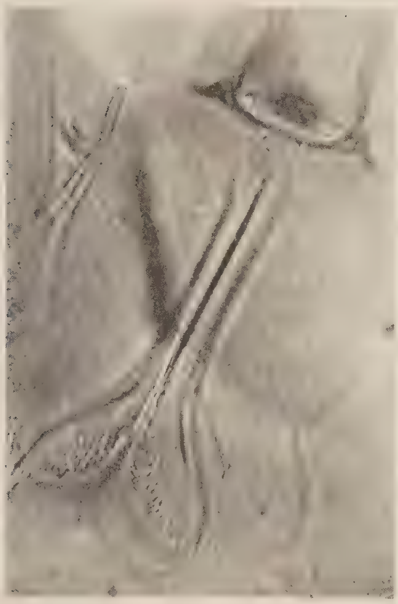

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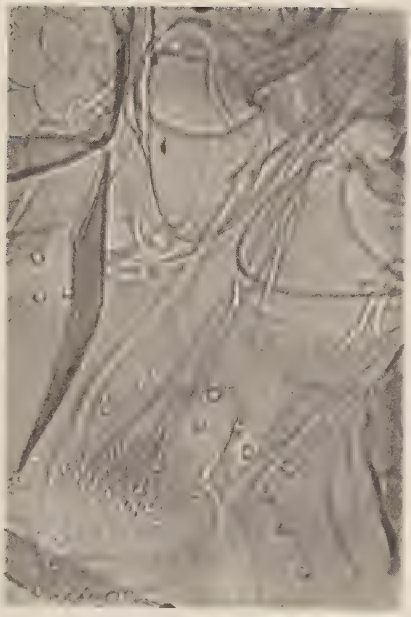

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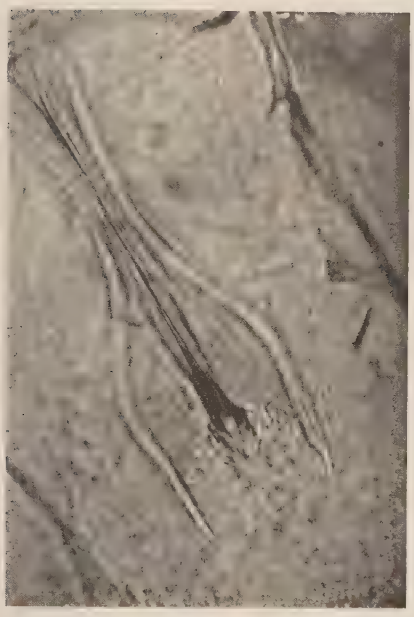

Fig. 3

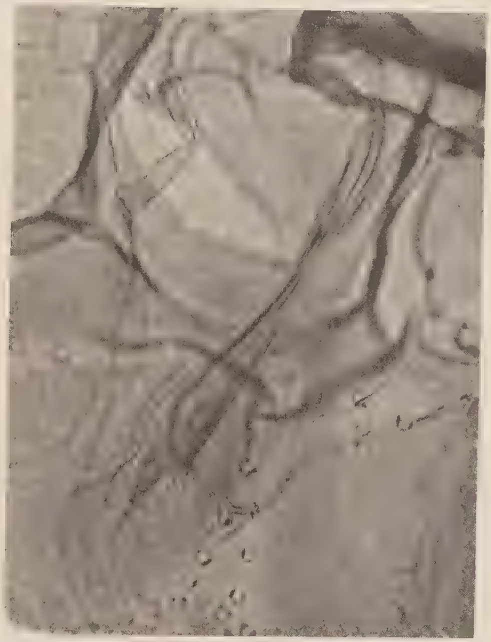

Fig. 4.

Fig. 1. Pharynx of *P. fallax* var. *cypriotica,* nov., ♀.

Fig. 2. Pharynx of *P. azizi,* Sp.n., ♀.

Fig. 3. Pharynx of *P. parroti* ♀ normal form.

Fig. 4. Pharynx of *P. parroti* ♀ melanic form: note reduction in teeth.

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ERRATA.

Page 12, line 20, for "*abtusifolius*" read "*obtusifolius*"
,, 49, 14 lines from end, for "*impexus*" read "*implexus*"
,, 94, line 26, for "*yanganbiensis*" read "*yangambiensis*"
2! ,, 114, 11 lines from end, and page 119, 12 lines from end, for "cellulose" read "cellulase"
,, 221, 2 lines from end, for "7·3" read "7·8"
,, 447, col. 4, 8 lines from end, for "*Papilia*" read "*Popillia*"
,, 488, Table VI, col. 3, line 8, for "*C. adersianus. A. fraseri.*" read "*C. adersia nus. T. fraseri.*"
,, 494, line 11, for "**43**" read "**44**"

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